BULLETIN

OF THE

SCIENTIFIC LABORATORIES

OF

DENISON UNIVERSITY

Volume XVI Articles 4–7 Pages 119 to 232

EDITED BY
FRANK CARNEY
Permanent Secretary Denison Scientific Association

GRANVILLE, OHIO, DECEMBER, 1910

STANDARDIZATION OF WELL-WATER IN THE VICINITY OF GRANVILLE, OHIO[1]

Lily Bell Sefton

The last few years have brought an increasing realization, both to scientists and to those entrusted with the sanitary welfare of the public, of the fact that the water supply of a locality has much to do with the health or ill-health of its inhabitants. In consequence, there is scarcely a city of any size that has not done more or less to better its water conditions. Filtration plants are being established, reservoirs are cleaned more frequently and scientifically, while the sale of distilled water has become a most profitable business.

It is unfortunate that this improvement is confined largely to municipal boundaries. What is true of a city with regard to its water supply is just as true of country districts. A contaminated well is as certainly productive of evil results as is a filthy reservoir or a polluted river. Moreover, when we remember that this well furnishes water for cattle, and that the cattle products are marketed in the large cities, it will be evident why these same evil results may be as far-reaching. It is highly important, therefore, that the farmer, as well as the city-dweller, know whether or not the water that he uses is pure. It happens that there is no fixed criterion by which the wells of different localities can be judged. Nearness to, or remoteness from, salt bodies, elevation above sea-level, differences, both chemical and geological, of soil, all combine to make it necessary for each community to have its own standard of purity.

The following analysis was made for the purpose of establishing such a standard for the wells in the Granville vicinity. Twenty samples were analyzed—samples taken from wells within a three or four mile radius of the village. The water was examined for dissolved solids, chlorine, ammonium, both free and combined, nitrates, nitrites, oxygen-consuming power and phos-

[1] This work was done under the direction of Prof. A. M. Brumback.

phates; and the analysis was conducted according to a scheme given by Leffman,[2] although it was found necessary to make several modifications of his plan.

Before the actual analysis began, all the reagents and solutions to be used were very carefully prepared and standardized. Just here it may be well to mention one thing, which was learned by hard experience, and without which it will be impossible to secure results in any way satisfactory. It is this: use absolutely ammonium-free (and this, usually, will be also nitrite-free) water in the preparation of all reagents. To secure such water, twenty grams of potassium hydroxide and five-tenths grams of potassium permanganate were dissolved in a liter of ordinary distilled water, and then the solution was re-distilled by means of a Kjeldahl apparatus. The water obtained was used in making up another and stronger solution of the same kind. Two hundred grams of potassium hydroxide and eight grams of potassium permanganate were dissolved in a liter of this water, and fifty cubic centimeters of this solution were added to every liter distilled afterward. Water will remain ammonium-free for only a comparatively short time, so the reagents must be made up immediately.

The water to be tested was collected in two-liter bottles, made of green glass and provided with tightly-fitting stoppers. Since the purpose of this analysis was to establish a standard of purity, samples were not taken from any wells save those thought to be pure. This was determined by ascertaining that the well was not located near, nor in any way connected with, such sources of impurity as barnyards, cesspools, and vaults; by making sure that no sickness had ever been traced to the use of the water; and by finding out how recently and why the well had been cleaned.

Three analyses were carried on at a time. Owing to the variability, from time to time, of the quantities of ammonium, nitrites, nitrates and oxygen-consuming power, these were tested for first, while the tests for chlorine, phosphates, and dissolved solids were left till later.

In testing for ammonium, standards containing a known equivalent of ammonia were nesslerized and then the first three or four distillates (similarly nesslerized) were compared with these. After the free ammonia had been driven off, the remainder of

[2] Henry Leffman, *Examination of Water for Sanitary and Technic Purposes*, 1895.

the sample was treated with fifty cubic centimeters of the alkaline permanganate solution, which converts into ammonia certain forms of the nitrogen contained in any organic bodies which may be present in the water. The amount of organic matter is thus indicated, and consequently the purity of the water. Leffman gives .123 parts per million as the highest possible amount of albuminoid ammonia allowable in pure water. It will be noticed that samples 4, 8, 12, and 22 greatly exceed this amount; but, since both 4 and 22 are wells of exceptional depth, it is probable that this is not indicative of impurity in them. Deep wells very often contain harmless ammonium compounds which increase the apparent amount of ammonium. Samples 8 and 12, therefore, come under suspicion. It is worthy of note, also, that in both 4 and 22 the oxygen-consuming power is correspondingly high, showing that the organic matter was of vegetable, and therefore of harmless origin; also that in all four cases the ammonia was given off slowly, indicating a slow decomposition of organic matter, which is not so harmful as a more active decomposition. The fact that in some cases the results obtained by adding the permanganate at once are higher than when the results of the two separate methods are combined, may be due to this—that in the latter case, some of the combined nitrogen is driven off in some other form before the permanganate is added.

Closely related to ammonia, in its significance, is the presence of nitrites and nitrates. Leffman, in his general standard, says that uncontaminated water shows little if any indication of the presence of nitrites.[3] It will be noted that the results from this analysis run from very faint traces to 1.23 parts per million. Since every sample is assumed to be healthful, we may safely conclude that well-water in the Granville vicinity may have as high as 1.23 parts per million and yet be considered pure.

There is a difference in the opposite direction with nitrates. Leffman allows as high as 1.25 parts per million; none of the samples analyzed, save two, gave more than .5 parts per million. Many of them show but traces. Since in both the exceptions (samples 2 and 10) there is no decided departure in other respects from the average, it may be concluded that these excesses are not suspicious.

[3] *Ibid.*, p. 93.

Leffman says: "The popular notion that hard waters conduce to the formation of urinary calculi is not borne out either by statistics or by surgical experience. . . . No absolute maximum or minimum can be assigned as the limit of safety."[4] The table below shows that the amounts ran from 28 to 807 parts, the difference being due largely to the difference in the deposits through which the waters have come.

Since chlorides are abundantly distributed in the soil and are in most cases freely soluble, a wide range of amounts may be looked for. But one sample (14) runs higher than 20.12 parts. Phosphates, on the other hand, while just as freely distributed as chlorides, are highly insoluble, so that we may expect, what we really find to be the case in this particular instance, very little, if any traces of phosphates. Both chlorides and phosphates are characteristic of animal excretions, hence an excessive amount of either or both with no apparent reason, is open to suspicion.

Mention has already been made of the oxygen-consuming power. The estimation of this gave much trouble, until absolutely ammonium-free water was finally used as a standard. Each sample and the standard was treated with acidified potassium permanganate and kept at a temperature of 96° C. for three hours. At the end of this time, by titrating with sodium thiosulphate, it was found how much oxygen had been consumed by the organic substances in the water. In but three of the samples was an excessive amount consumed. Samples 4 and 22 have already been satisfactorily accounted for, and sample 10 does not exceed the maximum limit according to Leffman.[5]

[4] *Ibid.*, p. 92.
[5] *Ibid.*, p. 99.

SAMPLE	DEPTH OF WELL	SOLID MATTER	CHLORINE	FREE AMMONIA	ALBUMINOID AMMONIA	TOTAL BY SEPARATE METHODS	TOTAL N AS NH_3	NITRITES	NITRATES	OXYGEN-CONSUMING POWER	PHOSPHATES
1.	Tap	528.	20.12	.0216	.0432	.0688	.0648	Slight trace	None	.216	Trace
2.	35	325.	18.5	.0456	.078	.1236	.1212	.012	4.	.121	None
3.	Cistern	31.	None	.0204	.0576	.0864	.062	.012	.2	.218	None
4.	187	458.	5.593	.1968	.2486	.4454	.4848	.08	Slight trace	1.872	Trace
5.	14	112.8	5.8002	.0024	.0888	.0912	.0936	Very faint trace	Faint trace	.0862	Medium trace
6.	48	113.2	7.4574	.0144	.1052	.1196	.1150	.33	Faint trace	.211	None
7.	85	171.6	15.74	.0284	.0288	.0572	.0600	Trace	Medium trace	.719	None
8.	28	200.	16.71	.032	.1416	.1736	.1656	.25	No trace	.234	None
9.	65	202.	2.28	.0336	.1128	.1464	.1408	Very faint trace	No trace	.0912	None
10.	25	548.	7.11	.0096	.1008	.1104	.103	.0532	2.	1.23	Trace
11.	30	28.4	6.835	.0144	.0516	.0660	.0672	.0568	Very faint trace	.865	None
12.	28	689.	12.5	.0126	.1416	.1536	.1608	.248	.5	.547	Faint trace
13.	54	466.4	15.12	.0108	.0768	.0876	.0864	.017	.5	1.111	None
14.	20	336.	60.07	.006	.0980	.1040	.1056	.017	.5	.834	None
15.	33	722.	18.71	.0144	.0492	.0636	.0600	Faint trace	Faint trace	.347	Medium trace
16.	125	807.6	10.49	.0252	.0564	.0812	.0816	1.32	Faint trace	.792	Faint trace
17.	35	608.4	9.1146	.0204	.0501	.0748	.0672	Very faint trace	None	.438	Faint trace
18.	32	418.8	6.69	.012	.0384	.0504	.0576	.99	None	.009	None
19.	44	654.	10.426	.012	.0432	.0552	.054	.66	Very faint trace	.918	Medium trace
20.	60	435.	9.735	.0264	.0684	.0948	.1102	.50	.2	.356	Medium trace
21.	32	217.	4.78	.0252	.054	.0792	.0754	.33	Faint trace	.212	None
22.	180	376.	11.24	.036	.246	.282	.2354	.25	None	1.594	None

CHAPTERS ON THE GEOGRAPHY OF OHIO

FRANK CARNEY

With this issue of the BULLETIN I begin the publication of some chapters dealing with the geography of Ohio. The chapters will not appear in the order proper to a unit treatment of the subject, but as particular phases of the study have been completed.

The method of treatment is an attempt at such comprehensiveness as the average public school teacher needs, but usually has neither the time nor the available literature to procure. Useful bibliographies and the necessary maps will be a part of the completed work.

It would be a time-consuming task to particularize my obligations to the literature. There is nothing new in these chapters; many of the facts were acquired from scattered sources at odd times during the last five years, with no thought of thus using them. The various publications of the State Geological Survey have been drawn on freely in discussing the economic mineral products.

To Dr. J. A. Bownocker, State Geologist, I am much indebted for the privilege of quoting from his publications on salt, and on natural gas. Particular acknowledgment is due Dr. George D. Hubbard, Professor of Geology, Oberlin College, for reading the manuscript, and making valuable suggestions.

TRANSPORTATION

Regardless of its mineral wealth, rich soil, waterfalls for energy, delightful climate, or any other natural advantage, unless a

region is easily reached it will make progress slowly. To appreciate this fact we need only to recall some section of the continent where it has long been known that great mineral wealth exists, but not being accessible, it has remained unexploited; other areas have very rich soils, but are still fallow, simply because they are not within easy communication. There is no incentive to mine ores, or to grow crops in excess of immediate requirements, if this excess cannot be marketed.

Ohio occupies a peculiar position in reference to the Atlantic states on the one hand, and the Mississippi valley on the other. Probably 90 per cent of the present-day commerce between these two sections passes through, or along the margin of, Ohio. Ohio is the backdoor of the more densely populated Atlantic states. For a long time, the Appalachians were a formidable barrier; the sea coast strip was easily colonized and largely exploited before colonists moved across the barrier. When congestion compelled expansion into the interior, natural routes were first utilized. The Mohawk lowland is the lowest pass across this barrier; through it pulsed the lines of emigrants, and later the traffic of stage routes, canals, and railroads.

Immigration routes. While to-day we regard the Mohawk lowland as the easiest route to and from the northern coast states, it is a curious fact that the earliest colonists into the trans-Appalachian region came by more rugged routes. The Cumberland pass, and the river-route from the site of Pittsburgh, were first used. The Mohawk pass was itself so inviting an abode and it opened upon such fertile plains in western New York that settlements were established there, before it was necessary to push out farther along Lake Erie. The emigration into northern Ohio is associated rather with political conditions than with this more easy line of traffic. Furthermore, the necessity for expansion arose earlier in the Atlantic states opposite Ohio. The first settlers in Ohio, as well as the first explorers, approached the state by the Ohio River. Peoples enter new regions by river valleys, where they exist; the earliest settlements therefore are valley towns. The first clearings for cultivation are usually made on flood plains. With the increase of population, lands are cleared in higher altitudes. This is a matter of convenience; river valleys afford natural grades for traffic, where it is carried on wheels, and the river itself welcomes boats. But in studying the location

of first settlements in some parts of the state, we find that this rule does not always hold. Some settlers chose the hilly regions even when the level lowlands might have been had. Whenever such a choice is made, it usually reflects a previous topographic environment of the settlers. Men reared among hills, when coming into new areas, select similar topography. From the Ohio river, extending far north through the state, are several important river valleys; the earliest towns were founded along these rivers.

Early prosperity. Commonwealths have to learn how to accumulate wealth. A state may have an ample rural population, and yet have no particular rank among commonwealths. Its property may be owned by individuals and be unencumbered. Indebtedness may be generally abhorred by its citizens, and yet among states it may be counted very backward. For a state to be effectively prosperous, its citizens must accumulate more than their homes and farms. It is the excess wealth that counts. Ohio has always been an agricultural state. In its early history, farmers had to be contented with growing enough to support their families and slowly accumulating money to pay for their homes. There was only one way in this early period for them to acquire much more than this. It was quite impossible to reach larger markets, because there were no facilities of transportation. Hence there was little to be sold for cash. The simple needs were usually met by barter. This condition did not apply so stringently in the parts immediately adjacent to the Ohio and its larger tributaries, but this was only a small portion of the state.

Farmers learned early that the easiest way to secure cash was to raise cattle which could be herded and driven to larger markets. In consequence, the first important position attained by any center of population in this state came through slaughtering and meat-packing. Cincinnati, for many decades the metropolis of Ohio, was also for many decades the center of the slaughtering industry in this country. Eventually the central and southwestern part of the state began to accumulate capital through the pasturing of cattle and feeding of hogs; while a wealthy aristocracy of middle men was developed in Cincinnati. A European traveler,[1] who visited Cincinnati in the early forties, alludes

[1] Sir Charles Lyell, *Travels in North America*, New York, 1845.

in his report to the "Pork Aristocracy" of that city. But Ohio made no great progress in the acquirement of wealth till ready lines of communication with the east were established. This came first through the construction of canals.

Canal construction. The canal-digging fever struck Ohio shortly after its outbreak in the Atlantic states. In 1817 its legislature considered the matter of constructing waterways; the subject came up regularly in the following years, culminating in 1825 in a law that commenced operations. In this same year Clinton's "ditch" tapped Lake Erie. The Ohioans, therefore, did not wait for positive proof of the advantages of improved waterways. The evidence was forthcoming, had it been necessary, for immediately after the Erie Canal had wedded the lake and the ocean northern Ohio felt a new throb of commercial life. Lake trade was stimulated, harbors were improved, wharves and warehouses constructed; and prices advanced on all commodities that could be conveniently reached. The Ohio legislature had taken the initiative without these evidences. In seven years the Ohio Canal, 360 miles long, was completed, connecting Portsmouth on the river, at the mouth of the Scioto, with Cleveland on the lake. The Miami Canal, joining Cincinnati and Toledo, was commenced in the same year, reached Dayton in 1830, but was not completed to the lake till 1845. Along either canal route trade activity shortly developed the sleepy villages into thrifty towns and cities. Later adjustments have left some of these places only a retrospect; the canal period was their heyday. Others, however, as for instance Newark, Coshocton, Massillon, Akron, Hamilton, Troy and Defiance, have continued to prosper under the conditions incident to the transfer of shipping from the canals to railroads.

The Ohio Canal, the course of which was controlled by other considerations than merely joining the river and the lake, makes an ascent of almost 500 feet. Its construction, relative to its length, was much more expensive than the Erie Canal, which ascends only 445 feet. The maintenance of the Ohio Canal also involved greater expense. For this reason, with the extension of railroad lines in the state, we find that by 1856 the canals of Ohio ceased to earn running expenses. During about twenty years, however, these canals were of great commercial importance to the contiguous parts of the state. Even upon the open-

ing of the canal from Dresden to Cleveland, the price of wheat advanced from 25 cents to $1.00 per bushel.[2]

Railroad building. These canals had barely been completed before Americans started earnestly to building railroads. The construction of canals was always expensive, and the country accommodated by them necessarily limited; relatively, the freight rates were cheap, but on account of slowness of transportation many crops could not be shipped. Some of the canals naturally were neglected; and the state's energy was given to building railroads.

When we speak of railroads to-day, we at once think of one or another of the great "through lines." In the early days of railroad construction, no one dreamed of even a trans-state road. Until recent years a through line always meant the consolidation of short independently owned segments. Local interest in railroad building in Ohio was lively from the start. Thrifty commercial relations emphasized the inadequacy of boating facilities. The efficiency of the Lake Erie and Erie Canal route was not questioned, but there were few canals in Ohio to give access to the lake. The first steam road to operate in the state (1836) had one terminus on the lake at Toledo, the other being at Adrian, Mich. Sandusky had no canal, but by 1839 it completed several miles of a railroad, "The Mad River and Lake Erie," towards Dayton, which point it reached in 1844. Ohio capital and enthusiasm for railway construction were abundant, as shown by the fact that in 1837 forty-three railroad companies were organized by state charters. Many of these roads were never built, but some of them have become the best lines in the state. By 1846 a road was completed from Cincinnati to Springfield, and, by 1848, through steam connection was made between Cincinnati and Sandusky. Columbus and Cleveland were connected in 1851, and during the same year a railroad was finished between Cleveland and Cincinnati. The next year a line was opened from Cleveland to Pittsburg.

Geographically, Ohio needed transverse railroads; the lake and the river were its natural thoroughfares to markets; the wide, fertile major valleys of the state trend north-south, and its products move almost by gravity to one outlet or the other.

[2] Henry Howe, *Historical Collection of Ohio*, vol. ii (1891), p. 325.

Ohioans, except the immigrant ancestors, never gave further thought to the "Appalachian barrier;" their commercial friends on the seaboard looked after building the east-west lines.

The rivalry of the Atlantic ports in establishing through railroad transportation to the Mississippi basin was thus an advantage to Ohio. The Hudson-Mohawk valley made the construction of a line a child's task for New York, but the Appalachians imposed on Baltimore and Philadelphia a herculean undertaking; the former city early recognized the limitations of canals. A citizen of Baltimore, in urging the undertaking, said:

> Baltimore lies two hundred miles nearer to the navigable waters of the west than New York, and about one hundred miles nearer to them than Philadelphia; to which may be added the important fact, that the easiest and by far the most practicable route through the ridge of mountains, which divides the Atlantic from the western waters, is along the depression formed by the Potomac in its passage through them.[3]

In 1828 construction was commenced at Baltimore on a line headed for the Ohio valley, but twenty-five years elapsed before this destination was reached by the Baltimore and Ohio Railroad, the difficulties of construction having been underestimated.

The next year, 1854, the Pennsylvania line reached Pittsburg, with which city Cleveland had been joined the preceding year. In 1852 a road was opened from Buffalo to Cleveland; the same year, one from Toledo to Chicago; and the next year through traffic was made possible from Buffalo to Chicago. In 1857 a road across southern Ohio and on to St. Louis was completed; this was practically a continuation of the Baltimore and Ohio Railroad. By 1860 Ohio had what was considered in that day very ample railway facilities, a condition which contributed largely to the position that the state at once took in manufacturing.

When men were first building railroads, the matter of dividends was not as carefully thought out as nowadays. Knowledge came with experience. Usually the railroad fever struck a section of the state, and a railroad was built somewhere. More

[3] Philip E. Thomas, quoted in Johns Hopkins University *Studies in Historical and Political Science, Third Series* (1885), p. 99.

often than otherwise, bankruptcy closed the venture. Each road, built in the last two decades at least, shows that it was to meet already existing demands for freight hauling and transportation, or else that these demands were so obvious as to be realized at once on the completion of the road. Usually objective points existed, which the road entered. These were the "through lines" from which, to other objective points, branch roads were constructed.

The objective points, however, of these through lines are not always cities but more often regions, the business of which focuses in a city. It is fortunate for Ohio that its position necessitated roads being built through it, that they might connect these larger objective points. We have already learned that a few short segments, built by local capital, were incorporated into some of these through lines; but Ohio's money went rather for building roads transverse to these, acting as outlets and feeders for communities away from the larger roads. At these junction points were developed "railroad towns;" here were the railroad shops and homes for the men employed by the road. Later, if more roads passed across the same community, it became a "railroad center."

The presence of these roads usually inspired rapid growth, and a city in time developed. It appears, therefore, that the primary reason for the location of our larger railroad lines is not found in human activities along its route preceding the railroad. The course of the railroads was determined by the cost of constructing road beds; in parts of the state there were some deep gorges and valleys to be bridged. The route was to some extent a matter of topography. If the towns were in the way or could be reached without serious change in the route, they were passed through, but ordinarily the road was not being built for these towns. Later, as the result of the railroad, many such communities became populous centers; manufactories were built; distribution points for goods from the outside were established; warehouses, and storehouses for shipping of local products were constructed. Thus, in a few decades, a railroad, that was built through a region of scattered population, leads from city to city. Later other roads are built to these same centers, but not for the same reason that the initial road was constructed; secondary reasons have become active. These other roads represent capital that desires profitable employment.

Here are two cities, already busy places, but on separate "through" roads. Naturally business is carried on between the two centers. This could be done with greater facility if there were a connecting road. The road is built with profit. Again, one of these cities uses much coal for manufacturing. In another part of the state are mines in operation, which could produce far more coal if there were a greater market. That city is now getting its coal by a circuitous route from another coal-producing region. Capital sees profit in connecting the former mines with that city, and a road is built. Railroads have also been constructed largely for supplying an outlet to a large farm region; some secondary reason may have been present, but, operating with this immediate secondary reason, there is always the hope that the roads built will inspire development along their routes, which will insure still greater profit. Furthermore, some roads are built solely for hauling coal, others for hauling ore. The former, more often, are spurs or branch lines from railroads already in operation. As illustrative of the latter, reference should be made to the Lake Erie and Pittsburgh route, connecting the city of Cleveland with Pittsburgh. Iron ore is brought down the lakes cheaply, and unloaded at one of several ports in northern Ohio. The reduction plants of Pittsburgh and elsewhere along the upper Ohio River are dependent now on Lake Superior ore. These plants have coal near at hand. Some of them were constructed when ore in that immediate part of the country was being mined plentifully; then they had both the ore and the coal; now they have to get the ore from a distance. The cost of landing the ore at a lake port is not great, but it is expensive to haul this ore across Ohio, and the expense of transportation is dependent to a great extent on the grade of the road bed. Therefore, this road, recently constructed, has been located with but one end in view, that is, to obtain the lowest possible percent of grade. The expense involved in making cuts or in building bridges appears not to have been considered. A low grade, regardless of other factors of location, apparently determined the route.

When we consider the increasing number of blast furnaces appearing along Lake Erie, we naturally wonder what will eventually be the outcome of the competition between the old centers of ore-reduction and the lake front.

A railroad map of Ohio to-day is indeed a network. This

pattern is due to the development of numerous railroad centers. Cincinnati, Dayton, Springfield, Columbus, Marion, Lima, Toledo, Akron and Cleveland are focal points of many roads. These places lie north and west of the irregular topography of that part of the state where the Pennsylvanian formations outcrop. While, relatively, this part of the state has no high altitudes, at the same time, it does form something of a barrier between the lowland of the Ohio River and the lake plain on the opposite side. Most of the roads which cross this high area follow natural depressions made by river valleys. These routes were cheaper from the standpoint of railroad construction, and they pass through towns that give business.

The gross railroad mileage in Ohio in 1908, including electric lines, was 14,471.43. This gives an average of 0.352+ miles for every square mile of area. The following table shows how we compare with other states of the Mississippi valley in both the gross mileage of steam railways and the miles per square mile of area.

	AREA	MILEAGE	PER SQUARE MILE
Ohio[4]	41,060	9,111.27	0.221+
Indiana[5]	35,354	7,326	0.202+
Illinois[5]	56,665	12,796	0.218
Missouri[5]	69,420	8,141	0.117+
Nebraska[5]	77,520	6,083	0.077+
Iowa[5]	56,147	9,865	0.178+

There are still some sections of the state that are not convenient to railroad routes. These lie mostly within the area of the "Coal Measures." More roads are bound to be built in these parts. The coal deposits in time will be worked, if not for distant shipping, at least for local manufacturers. As the population of the state increases, the present neglected rougher areas will be occupied, and grazing or agriculture will be developed. This should also occasion railroad building in these parts. Furthermore, still more roads will probably be constructed between the lake ports and the Ohio valley steel centers. I believe, however, that in time the number of steel plants along the lake front will increase at the expense of those in the Ohio valley. Well estab-

[4] *Annual Report Ohio Railway Commission*, 1908, p. 402.

[5] *Railway Statistics of the United States of America for 1908*, p. 21.

lished industries die slowly. It is cheaper to haul coke to the lake than to carry ore from the lake to the older plants. Topography is a silent partner in industry; it never goes bankrupt.

Electric railways. The last decade has witnessed in Ohio a new phase of transportation. Trolley lines were first built in cities for passenger service. Then urban extensions were made. Gradually these grew longer. The urban lines of cities not widely separated met each other. Other places were then purposefully joined. Electric lines were built between still more distant centers. Now one speaks of "through" electric routes as we formerly did of "through" steam railways. Traction lines no longer depend entirely upon passenger service for income. They have taken on freight and express business, not only with profit to the investor, but with great convenience to the localities served.

No service of capital in modern times is doing so much to make living in the country more convenient. It is too early yet even to classify the changes of modern business methods, due to electric lines that are gradually extending over the state. These routes are encouraging more profitable phases of agriculture. They afford prompt service, making it possible to market perishable crops; and the centers of population thus served are equally benefited.

Better highways. Nowadays we hear much about highway improvement. Our legislatures, for a few years, have been making annual appropriations for the betterment of highways. Municipalities have been taxing themselves, that they might improve the roads leading into their immediate rural sections. Long ago it was the opinion of statesmen that the federal government should do this kind of work. The National Road which crosses this state is a product of that feeling. In the year 1811, this road was started from Cumberland, Md.; by 1818, it was completed to Wheeling, W. Va.[7] A dispute arising as to the constitutionality of the government's undertaking, the construction of the road was suspended till 1825; then an act was passed, making an appropriation for its extension to Zanesville. From Wheeling to Zanesville, a thoroughfare had long been in use; this had been authorized by an act of Congress in 1796, for the benefit of early settlers in Kentucky and the

[7] Ohio Archeological and Historical Society Pub., vol. Ix (1901), p. 435.

southwestern part of Ohio, whose journeys eastward through Pennsylvania were frequent, but very difficult either by the up-stream river route, or by the old "Wilderness Road." West of Wheeling, the National Road followed this highway, called "Zane's Trace," to Zanesville. By 1833, the National Road reached Columbus. Without much delay it was continued through Springfield into Indiana.

I suppose the Roman roads and later road-building of European countries furnished the suggestion for this undertaking by our government. The advantages of the national road were never questioned; but the fact that the original plan, to carry it through to St. Louis, was not accomplished may imply that the returns were considered inadequate for the investment. It is unfortunate that a people, which early recognized the advantages of good highways, should have forgotten them as soon as they commenced to build canals and railroads. Only in recent years have we come again to recognize the advantages of cheapening the cost of natural products by making less expensive the first part of the haul to markets.

In Ohio we have much valuable limestone. We have no crystalline rocks, except the "nigger heads," the material that is used so extensively for roadbeds in New England. But with our limestone, and selected sandy lime formations, it should be possible to make durable roads. I have noted that most communities are startled at the great expense of building even the cheaper roads. It is felt that large sums are required for the kind of roads being constructed. Another generation may justly accuse us of squandering it. It is far cheaper to spend double the amount which is being put into some of our highway improvements, thus getting a roadbed that with a slight annual expenditure would endure for generations. It is unfortunate that Americans cannot look at the matter of building highways as do some European states.

THE ECONOMIC MINERAL PRODUCTS OF OHIO

INTRODUCTION

Agriculture alone can give a commonwealth a high position. But the crop-producing capacity of a soil is in no wise diminished by the fact that mineral wealth may underlie the area. Agricultural states, having mineral wealth, are thereby the richer. Early in its history, Ohio took a foremost position in the production of minerals. While its rank in reference to particular minerals has shown great change, it still outranks other states in some valuable products. The earliest explorations in Ohio appear not to have had for an object the discovery of minerals. The first settlers came into the state to establish farm homes, and the early exploitation of its minerals was made to satisfy local demands that could not very well be met otherwise. The iron ores were worked at first to supply the needs of households and farms. For this reason the iron mines in Ohio were of great importance during its early decades.

IRON

Three classes of iron ore have been worked for this mineral in the state. The most conveniently handled of all perhaps was that obtained from bogs, though a furnace for reducing this kind of ore was not erected until 1824. Nearly all the bog ore furnaces were built in the northern part of the state near the shorelines of the ice-front lakes. The ore is thought to have been deposited by spring water which combined chemically with certain organic products of bogs, making a precipitate of iron. This source of iron never proved very profitable, consequently it was not able to compete with other ores.

In connection with certain clastic beds of the lower Pennsylvania formations, many iron stone concretions occur. These appear to be nodular clay products in which the iron has been assembled; possibly the iron concentrates made the concretions. Through the weathering of these horizons the matrix rock is more easily disintegrated; the concretions endure, and are found along slopes and stream courses. The earliest furnaces using this ore gathered their supply chiefly from valley bottoms. The supply being limited, these furnaces did not continue long in operation.

The most valuable iron ore that has been worked in Ohio is a limonite, first found as pockets or depressions on the upper surface of the Niagara limestone; sometimes many tons of ore were removed from a single body. The second blast furnace built in the state, along Brush Creek, in Adams County, used these ores. Other furnaces were shortly put up in the same area. Later they ceased to be profitable, because of the higher grade ore found in the Hanging Rock region of Lawrence County. This was also a limonite, but instead of occurring in pockets, it existed as continuous beds at several horizons in the lower Pennsylvanian formations. The Hanging Rock limonite is a weathered carbonate of iron. In weathering, the iron is hydrated by the action of ground water or of the atmosphere. These beds bear limonite for some distance below their outcrops, but blend gradually into the unaltered carbonate ore.

Early furnaces. The first blast furnace in this state was founded in 1806 at Poland, in Mahoning County, and commenced making iron in 1808. This furnace used the nodular clay iron-stone

of the coal measures. The second furnace, built at Niles, in Trumbull County, began operations in 1809. Within a few years numerous furnaces were erected in the ore-bearing regions. All of these had a precarious existence; many of them were operated intermittently, changing ownership frequently. The supply of the ore sometimes gave out and sometimes it produced an inferior iron.

Not until 1826 was the iron reduction industry in the state of Ohio put on a firm basis. In this year the Union Furnace was built in Lawrence County. The carbonate ores of the Hanging Rock region have proved the most valuable of any we have. This area shortly became the center of the iron mining and reduction industry in the state. The following table, prepared by Prof. N. W. Lord,[1] gives some statistics showing the development of blast furnaces in Ohio:

WHEN BUILT	NAME AND LOCATION	BUILDERS OR OWNERS	ABANDONED
1808	Yellow Creek Furnace, Mahoning Co	Clendenin, McKay and Montgomery	
1809	Mosquito Creek Forge, Niles, Trumbull Co.	James Heaton	1845
1811	Brush Creek Furnace, Adams Co		1826
1812	Mosquito Creek Furnace, Niles, Trumbull Co.	James Heaton	1857
1813	Yellow Creek Falls Furnace, Mahoning Co.	Daniel Eaton and Sons	1833
1816	Middlebury Furnace, Summit Co	Aaron Norton	1842
1816	Brush Creek Furnace, Adams Co		1826
1816	Marble Furnace, Adams Co		1826
1816	Mary Ann Furnace, Licking Co	Owned by Dille B. Moore	
1816	Little Cuyahoga Forge	Asaph Whittlesey	1850
1824	Geauga Furnace, Painsville	Used bog ore	
1825	Concord Furnace, Concord, Lake Co	Burned down	
1825	Railroad Furnace, Perry, Cuyahoga Co	Thorndyke and Drury	1833
1825	Arcole Furnace, Madison, Lake Co	Root and Wheeler (bog ore)	1851
1826	Union Furnace, Lawrence Co	Sparks, Means and Fair	1854
1823	Franklin Furnace, Franklin P.O., Scioto Co.	James F. and Oran B. Gould	
1828	Junior Furnace, Junior P.O., Scioto Co	Gliddin, Murfin and Co	
1830	Fairfield Furnace, Fairfield, Tuscarawas Co.	Owned by Zoar Community	
1830	Tuscarawas Furnace, Fairfield, Tuscarawas Co	Christmas Hazlitt and Co.	1846
1832	Arcole Furnace, Madison, Lake Co	Wilkeson and Co. (bog ore)	1851

[1] *Geological Survey of Ohio*, vol v, (1884), p. 450. I use the table only up to the year 1840.

1832	Clyde Furnace, Madison, Lake Co	Clyde Co	1838
1832	Elyria Furnace, Elyria, Lorain Co	Herman Ely (bog ore)	1835
1832	Conneaut Furnace, Conneaut, Ashtabula Co.	Bog ore	
1832	Elyria Forge, Elyria, Lorain Co	Norton and Barnum	
1834	Dover Furnace, Dover, Cuyahoga Co	Cuyahoga Steam Furnace Co. (bog ore)	
1834	Vermillion Furnace, Florence, Huron Co	Geauga Iron Co. (bog ore)	1840
1835	Mill Creek Furnace, Youngstown, Mahoning Co	Owned by Dan Grier	1850
1835	Middleburgh Furnace, Berea, Cuyahoga Co.	D. Griffiths and Co	1850
1836	La Grange Furnace, Ironton, Lawrence Co.	Ohio Iron and Coal Co	1856
1840	Akron Furnace, Akron, Summit Co	Ford, Tod and Rhodes	1855

Early methods. For several decades the reduction of iron ore depended upon charcoal; limestone for flux was abundant in the neighborhood of most furnaces. The heavily forested areas supplied timber for making charcoal; in some parts of the state the forests were removed anyhow to make way for farms. In the rougher sections of the state, the deforested lands were of little or no account. The use of charcoal in reducing iron ores has always been expensive, if one has consideration for future generations. It has been estimated that to run one blast furnace a year requires 13,000 cords of wood, which represents the timber of 325 to 350 acres.[2] Another estimate shows that to furnish a constant supply for one blast furnace, from four thousand to five thousand acres of woodland is necessary. Even this, to insure a stable supply, would necessitate taking much care of the second growth. The expensiveness of this process appealed to early workers. Mr. C. Briggs, an assistant geologist of our first survey, in 1838, in connection with his report on the iron ores, commented on the preservation of our forests.[3]

It became evident early that the supply of wood for charcoal would give out, thus putting an end to the reduction of the iron ores. Many of these furnaces were in the neighborhood of coal veins but the raw coal had not been tried. Necessity, however, forced a furnace owner either to abandon his plant or to experiment on this possible fuel. Consequently in August, 1846, at Lowville, in Mahoning County, "rock coal," as it was called, was first used in the raw condition in this state. It proved fairly

[2] *Ibid.*, p. 483.

[3] *Geological Survey of the State of Ohio, First Annual Rep.* (1838), p. 93.

satisfactory. Only one other furnace in this country had anticipated this use of raw bituminous coal; the Clay Furnace at Clarksville, Mercer County, Pennsylvania, had used it the summer before. Even after experiment had demonstrated that raw coal would answer the purpose in blast furnaces, it was a long time before the majority of plants discontinued the use of charcoal. In many sections they were already cutting the second-growth forests, and in some localities furnaces had insisted on using charcoal, with the result that the woodlands had been cut for the third time. On a small scale, coal was being coked for a blast furnace at Akron in 1837.[4] I have not been able to ascertain how long coke had been in use.

Products. I have already shown how local necessity led first to the reduction of iron ores. In many cases the molten iron was cast directly from the furnaces into the molds of cooking utensils, stoves, etc. Other uses were soon discovered; charcoal forges were built usually in close proximity to the blast furnaces. These forges turned out malleable or bar iron. Shortly after this, rolling mills and foundries were built at points more distant from the mines. The charcoal pig iron from the Hanging Rock region in particular early obtained a wide reputation. It was shipped to distant points, and had an extensive use at Pittsburgh for manufacturing government ordnance, and later for car wheels.

Decline of industry. By 1856 Lake Superior ores were commencing to be shipped regularly into the northern part of the state. This ore contains a much higher percentage of iron than our native ores. Consequently the furnaces so situated as to conveniently secure the Superior ore gave up entirely the use of the local supply; and other furnaces were put out of business by the competition. The use of Lake Superior ore spread southward through the state, until eventually the native ores were reduced only in the Hanging Rock and Ironton regions. Among the iron-ore producing states in 1907, Ohio ranked seventeenth, supplying but five per cent of the bulk and three per cent of the value of the country's output.

[4] *Geological Survey of the State of Ohio,* First Ann. Rep., p. 18, 1838.

BUILDING STONES

Not all rock, not even all that appears durable when first quarried, makes a suitable building stone. Neither is it true that for building purposes the best stone is always used. Quite as important a factor as durability, ease of working and appearance, is the convenience of getting stone to market. Many important quarries have been put out of business by the opening of others which were more available. In building stone production, Ohio has maintained an important position for many decades. Stone from its quarries has been shipped to all of the central Atlantic states, as well as into the Mississippi basin states.

Important properties. A stone must be strong enough to sustain the weight to which it is subject in a building. This property is termed "crushing strength," which refers to the number of pounds pressure per square inch required to break the stone. Few stones, however, have been found unequal to any ordinary weight which they would be called upon to sustain in regular building processes. Even a structure like the Washington Monument imposes on the stone of its base a weight of only a little above six thousand pounds per square inch. The crushing strength of average sandstone runs from six thousand to thirteen thousand pounds. The finer grained limestones frequently have a much higher crushing strength. In reference to this property, the highest grade stones are the granites and crystalline igneous rocks of which we have no quarries.

For many purposes, it is very necessary that a stone be hard, or else become hard when exposed in buildings. Certain sandstones may be crumbled even with the fingers. The particles of sand, being quartz, are themselves very hard, but the "hardness" of a clastic rock depends upon the manner in which its components are cemented together. It is quite immaterial how hard the individual particles are, unless they are firmly knit together the stone will not be hard. The usual cements are lime, silica, and iron. The more common cement of sandstone is silica; sometimes, however, we find both iron and lime. In many sandstones, a trace of iron tends to discolor the stone.

While a stone may be hard, because its particles are closely cemented, at the same time it may be coarse-grained or fine-grained, depending upon its "texture." Furthermore a rock stratum may vary in texture, thus making it uneven. An even

fine textured rock is easily dressed and lasts longer. Its texture has had much to do in giving the Berea sandstone of many of our quarries so wide a reputation.

In general, the more durable building stones are those of highest specific gravity or "density." A porous stone naturally is more exposed to the weather. It absorbs moisture which in the winter season freezes and injures the stone. Other things being equal, the best building stone has a fairly high specific gravity.

Clastic rocks, to which class much of our building stones belong, represent the assembled components of older rocks. Under some conditions, small crystals may be developed in these clastic rocks. Usually, however, they are simply an agglomeration of worn particles of earlier rocks. Since minerals among themselves differ widely in color, it follows that clastic rocks also are vari-colored. Quartz, for example, is sometimes perfectly white, sometimes red. Feldspar is often red. Most of the biotite is dark. As a result, building stones vary in color, from prevailingly dark to buff and white. Sometimes upon exposure the color of the stone changes. This not infrequently occurs with sandstone carrying a small amount of ferruginous matter which oxidizes and gives the stone a rusty appearance. In walls of buildings, one block of such a stone frequently discolors quite a strip below it.

Limestone. The earliest building stone quarries in Ohio were opened in limestone horizons. Many of our limestones are admirably adapted to structural purposes. The depression of the Scioto valley, and the erosion that has taken place along the axis of the Cincinnati anticline, have combined to expose four ages of limestone, each of which has been used extensively for structural work. I will speak briefly of these four horizons, commencing with the earliest.

Above the Trenton formation, a very hard limestone occurs in the Hudson River group of the lower Silurian. This limestone is found usually in thin beds, quite uniform in thickness. The strata are generally separated by shale layers, which makes quarrying easy, but produces large waste piles. This limestone has had extensive local uses, but has never been shipped to very distant points. Its color and its crystalline surface make it desirable; while it is a little more difficult in dressing, at the same time when properly tooled it is a very pretty building stone. Doubtless the demand will increase as shipping facilities improve.

In the lower part of the Niagara formations, splendid stone for building purposes is found. This stone cuts well, particularly the Dayton phase which is quarried extensively in Montgomery, Miami, Clark, Greene, and Clinton counties, and to some extent elsewhere in the southwestern part of the state. In all of these districts many elegant buildings are made of the Dayton stone.

The Monroe formation of the lower Helderberg supplies a good stone, the "Springfield" stone, especially from the upper part of the formation. While this is quarried at several points, the principal workings are at Greenfield in Highland County, and Bellefontaine in Logan County. This formation is used extensively for crushed stone in road-making.

The Columbus formation of the Devonian furnishes more building stone than any other limestone horizon of the state; the Delaware formation is also used; in the lower beds of each is found stone of the best quality. Extensive quarrying operations in these horizons are carried on at Kelly's Island, Marblehead, Marion, Delaware, and Columbus.

Sandstone. The early reputation of Ohio outside of the state, as a source of building stone, came through its sandstone quarries. The oldest period which contains this form of clastic rock in suitable condition for structural purposes, in the state, is the Mississippian; the Berea formation is the most extensively used. This stone has a color, a texture, and an ease of working, that account for its popularity. It is a very durable stone, and in general holds the original color, or changes color uniformly under exposure. In the early days the Berea workings were developed near growing towns. Even the outcropping edges of the beds, which had weathered into loose blocks, were worked roughly and carted miles into Cleveland. Some farmers made a business of supplying local demands, and did the hauling during the season when the farm work was slack. Later regular quarrying operations were begun; teams and oxen were still used for transporting the stone. With the appearance of railroads and the opening of the new quarries adjacent, the old ones gradually lost trade.

The Berea formation comes to the surface in a general north-south strip through the state. In the vicinity of Cleveland its outcrop trends slightly to the southwest, and then directly towards the Ohio river. At Cleveland, Berea, West View, Columbia Station, Grafton, Amherst and Berlin Heights are found the princi-

pal quarries now in operation. Formerly there were several other openings, some of which were worked at a very slight profit, and a great deal of needless competition prevailed. The Cleveland Stone Company is a combination of many owners. With this combination, better quarrying methods have been introduced, and only the openings in good quality of stone were retained. There is no question but that more modern business methods have been used to the advantage of builders, though many quarries have had to go out of business. The stone is put on the market in better shape, and probably of more uniform quality.

The Berea formation affords an exhaustless supply of desirable building stone. The quarries now in operation show a variation in thickness of good quality of stone from 20 to over 100 feet. The deepest quarry is at South Amherst. The oldest are those about Berea. Many of these quarries furnish stone well adapted to abrasive purposes, a use which I described in another section (p. 156).

Several formations, other than the Berea, also supply good sandstone for structural uses. Only a little younger than the Berea is the Cuyahoga, which in the central part of the state embraces clastic beds of sufficient thickness and uniformity of texture to make a good building stone. In general, however, the Cuyahoga contains such thin and irregular beds that the quarries in it are not numerous. Belonging to the upper part of the Mississippian period, the Black Hand formation locally has many quarries. The Black Hand belt, which contains stones suitable for building purposes, extends north-south through several counties. This formation is much more irregular in texture, hardness, and structure than the Berea. It varies all the way from a coarse conglomerate to an argillaceous sandstone. Usually, too, it carries a higher content of ferruginous cement. In the earlier days some quarries of the Black Hand formation acquired much reputation; the Lake Erie and Ohio River Canal passes across its outcrop, and quarries were opened in it for making locks. The early railroads through the central part of the state likewise distributed building stone from Black Hand to more distant points.

In the lower formations of the Pennsylvanian period are some sandy horizons, in which building stone of average quality is found. The best, perhaps, occurs in the Sharon phase of the Pottsville. This outcrops in a band usually parallel to the Black Hand out-

crop. All these formations dip to the east and south; thus they appear as shingles over one another. To some extent, sandstone has been quarried from formations higher up in the Pennsylvanian, but so far as I know, only for local use.

Flagging stone. This use, perhaps, may as well be mentioned in connection with building stones. Decades ago, certain quarries in the northern and north-eastern parts of the state had a wide reputation for the high grade of flagging stones furnished. Shipments were made to distant points. These quarries contained beds thin enough and strong enough to cut up into right sizes to be laid directly for walks. Sometimes the uniform thickness of these beds and the absence of joints made it possible to remove slabs of marvelous size. There is record of one slab 5 feet wide, 3 inches thick, and 150 feet long, having been taken out of a quarry near Warren, Trumbull County.[5] In general, however, the beds were so irregular in thickness that much selecting had to be done in matching up slabs for walks. After the stone saw came into use these quarries ceased to be profitable. By the use of the saw, heavy beds of the Berea are divided into slabs of uniform thickness. In connection with several of the quarries now in operation, sawing is carried on many months of each year. The demand for stone flagging is still active, but, recent development in the use of cement promises that before many years the cement will occupy the field entirely.

Other quarry products. In *Mineral Resources* for 1908 it is noted that Ohio ranks second in its output of crushed stone,[6] and first in crushed limestone.[7] With the promise of greater activity in highway improvement, there will be an increasing demand for our limestones; this state has practically exhaustless calcareous formations, easily quarried and marketed. In the production of curbing stone, we rank second, and hold the same place in flagging. In both of these products, however, it must be expected that the market will decrease as cement comes more generally into use.

[5] *Geological Survey of Ohio*, vol. v, (1884), p. 580.
[6] *U. S. Geological Survey*, "Mineral Resources," 1908, p. 544.
[7] *Ibid.*, p. 575.

SALT

For a great many years, Ohio has been a renowned salt-producing state. Its rank, during much of the last quarter of a century, has been either third or fourth. In 1908 only two other states, Michigan and New York, produced more salt. No one knows just how long salt has been manufactured in Ohio. White men have been boiling brine in the state for over a century. The few salt licks early discovered by the first settlers were of great value to them.

Early development. Much interesting history is connected with this natural resource. This history, the geological association of salt deposits and the methods of working it, have been thoroughly investigated by the State Geologist, and so clearly described that I here quote from a recent publication of the State Survey:

Probably the first attempt to make salt on land now forming part of the state was in 1798. The locality was the old Scioto salt works on the banks of Salt Creek in what is now Jackson County. These salt springs were well known to the buffalo and other wild animals, long before the white man discovered them. Buffaloes came in herds, forming well beaten paths, recognizable as late at least as 1837. Regular pilgrimages to the licks were made by these animals until they were driven from the territory. That they were loth to abandon so favored a spot is shown by the fact that the last buffalo seen native in Ohio was near these licks, the date being 1802.

From earth works near the licks it has been thought that the Mound builders appreciated the locality as well as did the lower animals. Later the spot was a favorite with the Indians; the men killed the game which came for brine, while their squaws busied themselves making a little salt. Wells were not dug, the Indians simply taking the brackish water from the creek at low water stage and evaporating it. The last of their old salt pans was blasted out in 1899. Pilgrimages were made to the licks each summer by the Indians until about 1815.

The date of the white man's discovery of the licks is not known, but is was probably early in the eighteenth century by Canadian fur traders. The Virginia colonists knew of them at least as early as 1755. In 1795 a company of white salt boilers settled on the licks, and the camp is said to have grown quite large before the close of the century.

Officials of the federal government soon learned of the licks, and prompt action was taken to prevent their falling into the hands of parties who might make a monopoly of them. Thus in 1796 Congress passed an act providing for the sale of lands northwest of the Ohio River, but expressly reserved for future disposal the area containing these licks.

No arrangement was made, however, for operating the licks, but this was done a few years later when the territory became a state.

Early wells at these licks were quite shallow, varying from 20 to 30 feet in depth. The brine was correspondingly weak, from 600 to 800 gallons being necessary to make a bushel of salt. The product had a dark color and was otherwise inferior, but it was so much better than none that it commanded a high price.

Other pioneer wells were located on Salt Creek about nine miles southeast of Zanesville, on Duck Creek in Noble and Washington counties, and in the valley of the Muskingum. In all of these the salt industry started near the beginning of the nineteenth century, probably about the time of the state's admission into the Union. It is worthy of mention in this connection that several of these wells demonstrated the presence of petroleum and natural gas, though advantage was not taken of the discovery.

April 30, 1802, Congress passed the enabling act preparatory to Ohio becoming a state, the act providing, among other things, that an area of 36 square miles containing the Scioto salt springs shall be granted to the state for the use of its inhabitants. The legislature was empowered to frame regulations governing the use of the licks. The whole object seems to have been to prevent individuals or companies from obtaining a monopoly of them.

The first state legislature met March 1st, 1803, and soon considered leasing the salt licks. An act became a law April 13, 1803, which provided:

(1) That the state shall keep an agent for one year at the licks, who shall issue license to salt makers, collect the rent, study the geology of the region, and in other ways look after the state's interests.

(3) That no person or company shall use more than 120 kettles.

(3) That persons making salt shall pay to the agent three cents per gallon, payable quarterly, on the capacity of the plant.

April 14, 1803, the two houses met together and elected James Denny agent as provided for in the act referred to above.

In January, 1804, a second act relating to the licks was passed. This described more specifically the lots that might be rented for salt purposes, fixed the rent at four cents per gallon, and required the agent to inspect the salt. The rent was changed February 20, 1805, to two cents per gallon; February 13, 1808, to one cent per gallon; and January 19, 1810, to one-half cent per gallon.

The quantity of salt produced did not meet the expectations of the legislators, and an act was passed February 17th, 1812, to encourage deeper drilling. Similar acts were passed in 1813, 1814, and 1815, the last requiring a depth of 350 feet. It is reported that the honest driller went 100 feet deeper than the law required. A stronger brine was found, but the quantity was not ample.

According to Hildreth, the region was at its zenith of activity from 1806 to 1808, when twenty furnaces were in action, each averaging from fifty to seventy bushels of salt per week. When stronger brines were

found on the Kanawha and other localities, the Scioto licks were at a disadvantage, the result being that the industry languished and was finally abandoned.

In 1818 the legislature announced that the salt licks were no longer a success, and asked Congress to permit the state to sell the land. This request was not granted until the closing days of 1824. In June, 1826, a three days' public sale was held and all lands not sold during that time were disposed of privately.

The act of Congress which provided that the Scioto salt licks should be reserved by the state also provided that where other licks were found, the enclosing land, 640 acres in area, should in a similar manner be retained by the state. Under this provision it appears that one tract was reserved on Salt Creek in Muskingum County, and another one in Delaware County. These three localities were the only ones in Ohio known at that time where salt licks existed. These tracts also seem to have been disposed of by the state in 1826.

It is said that as late as 1808 the wells penetrated the mantle rock only. The first effort to secure brine in bedrock is reported to have been made in the valley of the Great Kanawha, near Charleston. At first these wells reached depths ranging from 70 to 80 feet, but later extended to 350 feet. The brine was found to increase in strength with the depth, a discovery of great importance. In some places, however, deep wells were not a success, for example those of the Scioto salt licks.

In 1817 drilling began in the Muskingum valley, the first well having been located a few miles below Zanesvillle. Two years later a well was drilled in this town, water furnishing the power. These wells, however, seem never to have been profitable. Farther down the valley results were more favorable, wells existing at short intervals for a distance of 30 miles. Finding that the strength of brine increased with the depth, wells were drilled 850 feet deep, when a brine of such strength was found that a gallon made one pound of salt. By 1833 this valley is reported to have produced between 300,000 and 400,000 bushels per year.

Among other places producing considerable salt at about that time may be mentioned Yellow Creek, Columbiana County, the valley of Hocking River in Athens County, and Leading Creek in Meigs County.

Drilling in those days was a laborious process. A hole from four to six feet in diameter was dug through the surface material into the bed rock. Into this hole, called the "head," was placed a hollow sycamore log known as the "gum," or in its stead a rectangular tube constructed of planks, to exclude surface water. At the lower end of this drilling began. In early years the spring pole was used, men furnishing the power. This was succeeded by the treadle, a horse doing the work. In still later years steam was used. During the first part of the century work continued as a rule day and night, the men working in shifts or tours of six hours each. Progress was very slow. It is stated that six feet were considered a large day's work. Caving was usually prevented by the insertion of a copper tube, though it does not appear that long strings of this tubing were used.

The salt was made by evaporating the brine in large iron kettles, each holding from 60 to 80 gallons. These were set in a row over a flue which terminated at one end in a chimney. The fuel was wood taken from the adjacent forests.

The brine was pumped from the wells into a tank constructed of wood, and connected by tubes made of the same material with the kettles. After having been boiled for a time the brine was dipped into a cistern where it was allowed to cool and settle. In this manner such material as had been mixed with the water in a mechanical way was deposited, and also oxide of iron, which was at first dissolved in the brine, but was made insoluble by boiling.

When the settling had been completed, the brine was again conveyed by wooden tubes to certain ones of the row of kettles, known as "grainers." Into these was thrown a small quantity of clay which served as a nucleus for any remaining impurities, the whole being skimmed from the surface of the kettles. Beef's blood soon took the place of the clay, and this crude method is still followed in one small plant.

When salt had been precipitated in the kettles by boiling, it was thrown into "drainers" and the mother liquor, containing principally calcium chloride, drained off. The salt was then dumped into a shed known as the "salt house," and the drying completed. It was then barreled and marketed."[8]

Geological Relations. For several years salt has been produced in two sections of Ohio: one near the Ohio River, centering at Pomeroy; and the other in the northern part of the state in Medina, Summit and Cuyahoga counties. The wells near the Ohio river seldom are more than 1600 feet deep. These wells get their best brine from the Berea formation, but a brine of lower specific gravity is found at two or three shallower depths. The brine is pumped to the surface and evaporated. East of Pomeroy, deeper drilling is required to penetrate the Berea formation, because of the dip of the strata. While at many points in the state, wells in the Berea give a brackish water, in few localities is the water sufficiently brackish to make salt reduction profitable. Not infrequently a farmer drills a well for drinking purposes, in the sections where the Berea is on or near the surface, and the water is so salty that it cannot be used for his stock.

The salt wells in the northern part of the state all penetrate rocks of the Salina series which contain numerous beds of rock salt. The wells in Medina and Wayne counties are about 2700 feet deep, while in the vicinity of Cleveland they seldom need to

[8] Dr. J. A. Bownocker, *Geological Survey of Ohio, Bulletin No.* 8, (1906), pp. 9-12.

go more than two thousand feet. The thickness of the individual beds varies from five to sixty feet. Water is pumped into the wells which forms a solute that is pumped out and evaporated. Some of the wells not far distant from each other have been operated so long that they now open into a single cavern which has been developed by the gradual solution of the salt, from the bottom of either well.

Origin of salt. Above the Silurian, the formations bear their salt in the form of brines, that is, saline water exists in the rock. It is possible that this brine represents small particles of salt originally deposited with the sediments; ground water, circulating at a later date, may have dissolved these small bits of salt, thus producing the brine. Again it has been suggested that the salt water, with which the sediment was saturated as it was deposited, may have been retained; this would be possible, provided the saline sediment immediately overlies an impervious bed and is also capped by an impervious bed; thus the brine would be imprisoned. When we recall, however, that jointing exists in almost all rocks, it hardly seems probable that imprisoned waters would remain in these sediments through much geologic time.

Much speculation has arisen from the great thickness of rock salt frequently found in some localities. In this country a homogeneous bed 325 feet thick has been bored through, but at Sperenberg, Germany, a bed 3600 feet thick has been reported. Geologists suggest that rock salt probably represents evaporation and precipitation in basins containing sea water, isolated from the ocean. As the water in these basins, shut off from tidal influence, evaporates, their level is lowered, and by the seeping through the isolating barrier, water from the sea is constantly added. This supply of sea water and its continuous evaporation would in time form a bed of salt, the thickness of which would be conditioned upon the continuance of the above factors. It is known that today several depressed areas contain bodies of water to which drainage is constantly being added, but from which there is no flow; the only escape is by evaporation; such bodies of water are saline, for example, the Great Salt Lake, Caspian Sea, Kara Burgas, Aral Sea, and the Dead Sea.

GLASS SAND

In recent years Ohio has attained an important position as a glass sand producing state. The rank, however, that any state may assume in reference to this natural resource is conditioned generally upon the development of glass factories within its borders. About twenty-five years ago this state began to produce gas extensively. As a result many industries were started, and among these the manufacture of glass. If it had not been for the natural gas of Ohio, it is doubtful whether the state would now rank fourth as a producer of glass sand.

Sources. Long before the discovery of natural gas fields some glass sand was prepared for the market. This came from the Silurian rocks outcropping in Lucas County. Interstratified with the Monroe formation at Sylvania, are beds of sandstone, 15 to 20 feet thick, which contain very pure silica. In 1863 quarries were operated at this place, the sand being shipped to Pittsburg for the manufacture of "pure flint glass,"[9] and later at Holland in the same county. These quarries doubtless contain the purest silica for glass sand of any in the state. More sand is prepared for the market, however, in the central part of the state, where the Mississippian and the Pennsylvanian rocks come to the surface. The Black Hand formation of the former period furnishes a quality of sand that is prized for certain manufactures. At Toboso a remarkably thick deposit of this rock is operated by the E. H. Everett Company; the sand there produced is used chiefly by the American Bottle Company at Newark. Other quarries involving either this formation or sandstone horizons of the Pennsylvanian period are worked in Perry and Hocking counties, particularly by the Central Silica Company of Zanesville. Quarries in Tuscarawas, Holmes, Summit, Wayne, Coshocton and other counties in east-central Ohio furnish the glass sand for local consumption; many of these glass plants, however, were forced out of business by a shortage in the supply of gas.

Preparation for market. After mining, the rock is crushed and ground, usually to the extent of reducing the sandstone to its original components. This loose sand is then washed, dried, and screened. The principal reason for the fine grinding and washing

[9] Gilbert, G. K., *Geological Survey of Ohio*, vol. i, (1873), p. 582.

is to get rid of certain impurities that make the sand less valuable; among these are clayey materials most of which may be washed away. In screening, the sand is often graded in accordance with different meshes; some of the plants market, as a by-product, the coarse material which makes fair ballast for roadways, or good gravel for concrete work. The sand from many of the quarries in the central part of the state contains iron, which makes it impossible to manufacture a light-colored glass. The product of these quarries is usually taken by factories that produce amber and green bottles. As a whole, the glass sand quarries of Ohio do not furnish raw material for the better grades of glass.

OTHER SANDS

Molding sand. Foundries use this sand in making molds for castings. The essential qualities of such a sand are: (1) It must be sufficiently aluminous to hold its shape when patterned to form a mold, as sometimes the patterns are delicate. (2) It must be refractory, otherwise the molten iron would fuse and spoil the mold. This requires a high percentage of silica in the molding sand, as quartz does not melt at such temperatures as will keep iron in a molten condition. (3) The molding sand must be coarse enough to allow gas to escape, but at the same time it must hold the molten iron in shape; and it should not contain much clay.

Many surface deposits in Ohio furnish excellent molding sands. Only New York and Pennsylvania produced more than Ohio in 1908.

Building sands. In the production of this sand, Ohio ranked fourth in 1908. It not only provides all used within the state, but ships to adjacent territory. Here again is a natural product, the marketing of which depends a great deal upon building trades. Where population is sparse, this sand would not be in demand. In the parts of the country where population is dense, and there is activity in building, great quantities of sand are called for.

Engine sand. In recent years the demand for this sand has been increasing. Formerly it was used only on those parts of railways and street car lines involving grades. The sand is sprinkled on the rail, thus increasing the friction surface and

enabling the car wheels to hold. Engines and street cars are generally equipped with sand bins, and the sand is sometimes used also on level stretches when the tracks are wet. According to *Mineral Resources* for 1908, Ohio ranked fourth in the production of engine sand.

Furnace sand. The demand for this is connected chiefly with the brick making industry; the sand is used between the bricks as they are placed in the kiln. This film of sand, which does not fuse under the temperature for burning brick, keeps the bricks from baking together. In still other industries, there is a demand for furnace sand. In the production of this sand, Ohio leads all the states.

LIME

According to the government reports for the year 1908, only Pennsylvania produced more lime than Ohio. Ohio contains a wide belt of limestone outcrops. These involve rocks ranging from quite pure calcium carbonates to a dolomitic amount of magnesium.

Formerly local kilns were operated at many points in the state. Now this industry is confined to certain centers, among which are Kelly's Island, Marblehead, Sandusky, Springfield, Cincinnati, and Marble Cliff near Columbus. This centralization is the result of modern business methods. Competition has led to the invention of machinery, which makes a great difference between the modern lime plant and plants of a generation ago. Not only the sources of raw material, but the shipping facilities for the finished product, are factors in the location of a lime plant.

The hydrated lime is to-day usually marketed as an impalpable white powder. This is the ordinary lump lime slaked, and powdered by grinding.

Uses. The various building trades require great quantities of lime, mostly as a mortar or wall finish. Several chemical industries also require lime. Much is used in the manufacture of glass, flint and plate glass particularly. Farmers have learned the value of lime on acid and clayey soils. Tanneries, paper mills, and sugar factories consume quite an amount of lime, as do also the manfacturers of basic steel, and of refractory brick. It enters also into the manufacture of soap and glycerine; its use as a disinfectant is increasing.

Sand-lime brick. In 1901 at Michigan City, Ind., an artificial sandstone or sand-lime brick was made. This new industry has shown a healthy growth. Some plants have been established in Ohio. Others doubtless will come into operation because of the abundant lime manufactured here.

This artificial sandstone is simply a combination of sand and lime. A comparatively pure sand is required; if the sand contains much clay, the product weathers more rapidly, especially in our climate. Usually coarse and fine sand are combined, three parts of the former to two of the latter; with one part of lime, twenty parts of sand are used. The lime is slaked, then the water and sand added, and thoroughly mixed. Later it is shaped into bricks, and hardened, generally by steam pressure.

With the widespread glacial deposits of Ohio and the high percentage of sands which they contain, it is natural that this industry should grow.

CEMENTS

Under this heading are included several mixtures each of which, with water, will make a mortar that hardens as a binder, that is, has cementing powers. The cement hardens or sets because the finely ground rock takes up the water and crystallizes or sets. The cement industry may be associated with the production of lime, though not necessarily. In this state three kinds of cement are manufactured.

In the production of cements, Ohio does not rank high. The position of any state in this product is conditioned by many factors. The cements are used as building materials, consequently the demand is greater near the larger cities, as activity in building is a matter of population. The mere fact that a state may contain abundant raw material for the manufacture of cements does not insure that plants will be erected. Competition is usually rife in supplies for building trades. Oftentimes the prosperity of a cement plant depends entirely on freight rates, which have to be figured in competition.

Natural cement. This is also called Roman cement, and Rosendale cement. It is made from a limestone which contains 30 to 50 per cent of clayey and sandy impurities. When this silico-aluminous limestone is burned, it will not slake unless finely ground. The ordinary carbonate, when burned, will slake in the lumpy

condition. Of the various cements made in this country this is the oldest. It was used for structural purposes early in the last century. Few plants are operating now in Ohio. The best, so far as I am able to ascertain, is that at Defiance.

Pozzuolane cement. This is a very old kind of cement. It was used by the Romans, as the name indicates. At first it was manufactured by combining slaked lime and volcanic tufa. The volcanic matter carried a high amount of silicic acid, which combined readily with the hydrated lime. In this country furnace slag which was cooled quickly is substituted for the tufa. This slag is a by-product of blast furnaces, and is usually discarded. A few furnaces, however, are now producing pozzuolane cement.

Portland cement. This is an artificial mixture of clay and calcareous matter. Any raw material which furnishes silica, alumina, calcium oxide, and some iron oxide, may be used. After these ingredients have been thoroughly mixed, they are burned to a clinker, and then ground fine.

Quite a variety of raw materials contain the required ingredients: clay and marl; clay, or shale, and limestone; pure limestone and argillaceous limestone.

The largest Portland cement plant in Ohio is at Castalia. Here they use travertine, a calcareous deposit of the springs that issue from the limestone in that vicinity, and soft clay. A plant at Middle Branch, in Stark County, uses a limestone and an associated shale. One in Logan County uses marl and glacial clay. At Wellston, Jackson County, is a plant built at some distance from the source of its raw material; the question of shipping facilities for the finished product decided this location.

ABRASIVES

Natural. For many years this state has led all others in the production of grindstones and pulpstones. The Berea formation furnishes most of this material. For use as a grindstone the rock must be homogeneous in texture, and its components must be sufficiently cemented to endure, but not so completely cemented that the stone will wear smooth.

Pulpstones are sometimes very large, weighing from two to four thousand pounds and even more, and measuring four to five feet or more in diameter. These stones must stand much heat,

since in grinding wood for pulp in the manufacture of paper, they are continually exposed to hot water. Formerly this country imported practically all of its pulpstones from England; now the Berea rock is found to answer the purpose.

Ohio also supplies scythestones and whetstones. These require a finer grained sand rock than will answer for either grindstones or pulpstones.

Artificial abrasives. In recent years natural abrasives have had to compete with artificial stones. Several of these are now being made in this country after German formulae; this competition is not important. A plant at Niagara Falls, however, is turning out a product with which our natural stones do not so successfully compete. Carborundum, the artificial abrasive there manufactured, was made possible by the supply of electrical current generated at the falls power plant. This abrasive is made by fusing together sawdust, granulated coke, the source of which is the carbonaceous residue in the distillation of petroleum, and a very pure glass sand. Only by the electrical furnace is it possible to secure commercially the required degree of heat. The fused product is ground to various degrees of fineness, and corresponding abrasive instruments are made, ranging from a fine razor hone to a very coarse tool. Since carborundum is harder than anything in nature, save the diamond, one appreciates how natural abrasives find this artificial product a strong competitor.

NATURAL GAS

Natural gas and petroleum are associated in nature, and man has frequently secured both from the same well. The reason for this association will appear in the discussion of their origin.

Early history. "Knowledge of the existence of oil and gas in the rocks of Ohio dates back almost to the period of the state's admission into the Union. This resulted quite largely from the search of the pioneers for that necessary article, common salt. Thus a well drilled in 1814, near the village of South Olive, Noble County, with this in view found such a pressure of gas that it threw the water and some oil to a height of from 30–40 feet, and these eruptions were continued as late at least as 1838. About the same time both oil and gas were discovered in Washington County to the south. The petroleum was called Seneka oil, and was used in a small way for medicinal, illuminating, and lubricating purposes. Similar results were secured at many points in the southeastern part of

the state, but the oil and gas were regarded as a nuisance. The former ruined the brine for the manufacture of salt, and the gas was regarded too dangerous. Deep wells, however, did not furnish the only evidence of this wealth stored in the rocks below. Sometimes ordinary water wells would liberate small quantities of oil or gas, and occasionally these products were found in still shallower excavations. At a few points oil was found as a very thin film on the surface of streams, and occasionally gas escaped with spring waters, the combination having been known as gaseous springs. It is interesting to note that evidence of this kind led later to tests at several points, with the result that valuable pools of oil and reservoirs of gas were discovered in Washington, Morgan and Knox counties, and finally the great Trenton limestone field itself."[10]

Pre-commercial use. Near Findlay, in 1836, a well was dug for water; at a depth of ten feet it had to be abandoned because of gas. Two years later a well was dug in the village; it also showed a strong odor of gas, and could not be used for water. The owner ingeniously inverted a sugar kettle over the top and conveyed the gas to his house through a wooden pipe, connecting it up in the fireplace by using the barrel of an old gun. In 1884 gas was still in use in this fireplace.[11]

At East Liverpool, in 1859, a well was drilled to the depth of 450 feet. It is probable that this hole was made for salt. Gas, however, showed, and no salt was found. In 1865 other wells were drilled, this time for oil, most of them producing some gas. In many instances the gas was regarded as a nuisance and the wells were abandoned. In one case, the gas was piped and used in a house or two and later in a pottery.

At Painesville, in Lake County, a 700-foot well was drilled in 1861. This was put down purposefully for gas which the owner secured in sufficient quantity to use in his home. The supply was still good in 1885.

Since 1865 wells have been drilled into the Ohio shale in Lorain and other counties along the lake, where this shale is near the surface. The supply of gas from these wells was in no case great, but usually ample for domestic purposes. Shallow wells are still being drilled in this area and most of them are successful. The fact that many houses have been continuously using gas from these shallow wells for cooking purposes and in some cases also

[10] Dr. J. A. Bownocker, *Geological Survey of Ohio, Bulletin 1,* (1903), p. 31.

[11] *Geological Survey of Ohio*, vol. vi, (1888), p. 109.

for heating is very suggestive of the advantage in conserving gas, as will appear in the following pages; there has been much recklessness and wastefulness in the use of gas in Ohio, as in other states.

Commercial exploitation. Inspired by the discovery of rich gas areas in adjacent states, people in Ohio, about 1884, commenced to drill deep wells. In locating these wells, there was very little judgment used, save where indications of gas already gave promise. Not infrequently the advice of men who knew the geologic structure and the probabilities of certain areas producing gas, was ignored. A spirit of reckless gambling pervaded most communities for several years.

At Findlay, however, there was already good reason for suspecting the presence of gas. Drilling began there in 1884, and by the end of the next year thirteen wells had been completed; some of these were big producers. Industries were attracted to the town by grants of free fuel for five years, and in some cases by grants of building sites in addition. Factories went up on all sides of the town which in less than five years increased in population from 5000 to 25,000. Reckless speculation followed, and gas was wastefully used, in spite of the admonitions of more judicial citizens. Many urged that nature was making the gas as fast as it left the wells, but by 1888 the flow from some of the wells was already diminishing.

The wells at and near Findlay led to drilling in adjacent territory. On all sides the drill was at work, and before many years men had learned the outlines of the paying territory. Several towns in the northwestern part of the state went into the gas business. In every case special legislation had to be secured at Columbus, allowing the municipalities to bond themselves to put down wells. Business competition led to these methods. The boom at Findlay encouraged Fostoria, Tiffin and other places to attempt the same thing. Manufactories were installed, and other wildcat projects sometimes encouraged.

It was found that the paying territory for gas wells extended northward from Findlay, through Bowling Green and North Baltimore. But in this whole area, by the year 1890, the gas flow had so declined that numerous factories either shut down, or removed from the towns. If some federal or state power could have imposed upon these communities an appreciation of this natural resource, they might have made more permanent progress

in consequence of its discovery. As it was, however, business disaster overtook scores of individuals, and numerous companies, as well as several municipalities.

South of Findlay, in the vicinity of St. Mary's, another gas field was located, and its early days had a similar history. In more distant parts of the state, the rapid growth of Findlay inspired communities to exploit their area. At Lancaster, gas was discovered in 1887, and this field, by further drilling, was extended both north and south; on the north it reached through Licking into Knox County, and southward into Hocking County.

Practically every county in Ohio, before the year 1890, was tested for gas. But in no location, so far as I can learn, was there any thought of conserving this resource. Even the doleful experience of the towns in the northwestern part of the state did not seem to drive the lesson home. So long as any gas flowed, much of it was wasted.

During the twenty-five years since the Findlay discovery several important gas areas have been found. Even yet, now and then, a new reservoir is located. But a more systematic study of nature's way of hoarding gas has tended to less hazardous testing.

Conservation. It probably is not far from the truth to say that as much gas has been wasted as has been used in Ohio. It is natural for capital to seek an immediate return. Men are tempted to get the largest possible yield from their investments in the quickest time. Human selfishness is not always wise, in spite of the fact that the progress of a race owes much to the law of survival. This waste of gas in Ohio, as well as in other states, has been allowed to continue already more than a generation. Field after field has given out. Factories have remained in one field until the gas was exhausted, and then some other community, discovering gas, has invited them there. Wildcat methods have been very common in connection with the use of this natural resource. In every gas community citizens will recall the details of waste. Only in the last two years is there noted a tendency to reserve gas for domestic purposes, but the movement has not assumed gratifying proportions; the largest consumers are supplied at a low price; manufacturing establishments are consuming in a few years gas that would be ample for a century of domestic use. Other fuels can be used conveniently in manufactories, whereas no fuel in houses can take the place of gas.

OIL

Early history. Along the Little Muskingum River, in Washington County, oil was found early last century, in connection with drilling for salt water. This matter was referred to in a letter written by Dr. S. P. Hildreth in 1818:[12]

> They have sunk two wells which are now more than 400 feet in depth. One of them affords a very strong and pure water, but not in great quantity. The other discharges such vast quantities of petroleum, or as it is vulgarly called, "Seneka oil," and besides is subject to such tremendous explosions of gas for several days that they made but little or no salt. Nevertheless, the petroleum affords considerable profit, and is beginning to be in demand for lamps, in workshops and manufactories. It affords a clean, brisk light when burnt this way, and will be a valuable article for lighting the street lamps in the future cities of Ohio.

In other parts of Ohio, early salt wells were not infrequently abandoned because they gave either gas or oil. It was seldom that either of these fuels were considered valuable.

The first dealers in crude oil in Ohio appear to have been "Bosworth, Wells, and Company" of Marietta. "The firm shipped oil to Pittsburgh, Philadelphia, Baltimore, New York, St. Louis, Peoria, Chicago, and Cincinnati. From 1848 to 1857 the firm received 33 cents per gallon for the oil, and from 1857 to 1860 40 cents per gallon."[13] At that time there were no refineries nearer than St. Louis. The oil was used for various purposes, but had always had some market as a medicine.

The famous Drake Well put down at Titusville, Pennsylvania, 1859, inspired testing in adjacent states. Within a year, many holes were sunk in West Virginia and Ohio. As in the case of gas, early prospectors were attracted by surface indications of oil, and usually did their first drilling in these localities. I will refer particularly to a few of these early efforts to secure oil.

Washington County. Near Macksburg, in 1860, a well was drilled 59 feet into the sandstone, and a very heavy oil was found. This oil was too heavy to burn in lamps, but had a ready market as a lubricant, commanding a price of $28.00 per barrel. Other wells in the immediate region were drilled at once. Great excite-

[12] *Geological Survey of Ohio, Bulletin 1*, (1903), p. 148.
[13] *Ibid.*, p. 149.

ment prevailed. Companies were organized and property changed hands frequently, at increasing prices. For a 200-acre farm, near the original well, $300,000 was paid. None of these early wells were great producers; not many of them flowed, but their shallow depth made pumping by hand relatively easy; the wells were drilled by hand.

At Cow Run, in 1861, the first well was sunk; at a depth of 137 feet oil was discovered. This oil was pumped by hand, two men being able to take out about 50 barrels a day. Here again great interest was aroused, and fabulous sums were paid for territory. The methods of these ventures almost seem beyond belief when read to-day. Even had a "gusher" been discovered, one could hardly understand the lack of business conservatism.

Noble County. Not far north of Macksburg, in 1860, a few wells were drilled along Duck Creek. Some oil was reported in most of them, and a moderate business was carried on. I find no record of such recklessness as prevailed in Washington County.

Trumbull County. Early in 1860, a few wells, ranging from 40 to 60 feet in depth, were sunk into the Berea sandstone near West Mecca. These are reported to have yielded ten to fifty barrels each at first; later, the daily yield dropped, and most of the wells were short-lived. It is interesting to note that, on account of the cheapness of labor, a farmer would get back his investment for sinking the well in case it produced two barrels. So far as I can learn, this is the only county in the state where men have tried to obtain the oil by mining; a shaft 52 feet deep was sunk, and from its bottom a tunnel was excavated 32 feet to the east, and 30 feet to the west.[14] These experimenters reasoned that if oil would gather into a six inch drill hole, more would collect in a tunnel. The venture was a disappointment. The Trumbull County oil area has only an historic interest.

Morgan County. The first well, 65 feet deep, was drilled in this county in 1860. It yielded eight barrels per day and continued to produce for twenty successive years. The well occasioned intense excitement; speculation at once became rife. A stock company with a capital of one million dollars was organized. One-half of the initial stock was sold in New York City; the remaining half shortly advanced 50 per cent in price. The 400-acre farm

[14] *Geological Survey of Ohio, Bulletin 1,* (1903), p. 301.

containing the original well was purchased for $375,000. Immediately another well was put down, which yielded twenty barrels per day. The spirit of speculation became more intense. Record shows that a one-half acre lot containing a ten-barrel well, sold for $10,000.

Wood County. As an oil field, this is the banner county of Ohio. The first oil, however, was discovered in drilling for gas, and occasioned very little interest. Drilling purposefully for oil commenced in 1886. Between the years 1891 and 1899, 7661 wells were drilled; 88 per cent of these produced oil. While in this county, no phenomenal gushers were found, it was uncommon to get a dry hole; the county is still producing much oil.

In other counties. The drilling for gas elsewhere in northwestern Ohio shortly disclosed the presence of oil. Among the very first wells at Findlay, oil was found. Usually, however, it was regarded as a nuisance. Some of the companies, upon failing to obtain gas in satisfying quantities, gave attention to the oil; as a result, these wells were pumped, and others put down purposefully for oil. That section of the state, since the gas so shortly gave out, was, in a measure, financially redeemed by the great abundance of oil. Many of the wells before long fell into the hands of companies that were more wisely managed, and northwestern Ohio received great profit from the oil.

The handicap of early wells. Following the year 1860, and the immediate boom in some sections of southeastern Ohio, the war had much to do in checking activity. Nevertheless, in the nature of things, these early wells were seriously handicapped. The oil produced, in many cases, had to be hauled several miles either to a railroad, or to a river, where it was transferred to boat. The method of piping oil had not yet been introduced. Piping methods, however, were introduced in time to make some of the territory more profitable. The Cow Run wells were piped to the Ohio River in 1868.[15] The tributaries had sufficient depth of water part of the year for floating boats, but the means of storing the oil were inadequate to work the wells the entire year. Nevertheless, all of the territory of southeastern Ohio became inactive, and for over a decade following the war little business was done.

[15] *Geological Survey of Ohio, Bulletin 1,* (1903), p. 154.

STRATIGRAPHY OF OIL AND GAS

Below I give a list of the periods and the formations in which the oil and gas of this state occur.

Ordovician. The oldest rocks in the state, producing oil or gas, are found in this period. The Trenton limestone is reached in the western part of the state at a depth of about 1100 to 1500 feet. This formation is found on the surface next to the Ohio River, but it dips towards the north, on account of the arching of the Cincinnati anticline. The Trenton oil and gas fields appear to be associated with this deformation. Elsewhere in the state wells have been sunk into the Trenton but without success. The farther east one goes, the deeper it is necessary to drill. The extreme depth of a well in this limestone is reported as 3440 feet; this well is near Ironton.[16]

Silurian. Two formations of this period have economic value. The Clinton sandstone supplies much gas in Knox, Hocking, Licking and Fairfield counties. Some oil also occurs locally in this sandstone. In Jefferson and Ashtabula counties gas is found in the sand horizons of the lower Helderberg; very little oil, however, occurs here.

Devonian. In one formation of this period, the Ohio shale, gas has been found for a great many years. This formation outcrops along the southern shore of Lake Erie, westward nearly to Sandusky. Probably no formation of the state contains so many wells. These are all shallow, seldom going over 800 feet. No one well has ever produced commercial gas, but has produced sufficient to supply one or a few houses. The wells are long-lived; it seems not unlikely that no formation contains more gas than does the Ohio shale.[17] The gas appears to be widely distributed in the formation, instead of being confined to a few reservoirs, as is the case in most gas-producing rocks.

Mississippian. Two formations of this period have commercial value in oil and gas. The Berea sandstone, which outcrops along an east-west line south of the lake, and then turns southward across the state from the eastern side of Huron County, dips to the east quite rapidly. In Washington and Monroe coun-

[16] *Geological Survey of Ohio,* vol. vi, (1888), p. 304.

[17] *Ibid.,* p. 413.

ties wells had to be drilled about 2000 feet, to reach the Berea.[18] The Berea has been drilled in widely distant parts of the state, and whenever penetrated it shows at least a trace of oil and gas, but has produced in commercial quantities only in the following counties: Lorain, Medina, Trumbull, Columbiana, Stark, Jefferson, Harrison, Belmont, Guernsey, Monroe, Noble, Vinton, Perry, Athens, Morgan and Washington.

The Logan group of the Mississippian, in Monroe and Washington counties, produces oil. These were oil centers of considerable importance in earlier days. The three horizons of the Logan that gave oil have been named by drillers in descending order: Keener sand, Big Injun sand, and Squaw sand. At only a few points outside of these two counties, does the Logan yield oil or gas in commercial value.

Pennsylvanian. Several sandstone horizons in the "Coal Measures" contain some oil and gas; each has a designation, usually a name associated with the locality where it was first found to be oil-bearing. The wide distribution of Pennsylvanian rocks throughout the state has led to much testing, but the successful wells are confined mostly to Noble, Morgan and Washington counties.

Occurrence in rock. An interesting fact in connection with these natural resources is their occurrence in such a variety of rocks. Both oil and gas have been found in limestone, in shale, and in sandstone, even sandstone that is conglomerate in structure. It is usually held that only in the porous zones of these rocks do we find oil and gas. Generally, only dolomitic limestone is gas-bearing; this phase of limestone is much coarser in texture, due to its crystalline structure, than is the purer calcium carbonate. The shale horizons are usually fissile and much broken by joints; while sandstone is always more or less porous. So far as the eye can detect, most of these rocks do not appear to be very porous, but, when examined under the glass, one is surprised at what a fraction of a given area the openings make. Sometimes a surface one foot square will show four square inches of combined interstitial spaces.

It has been found that oil and gas are not homogeneously distributed in any of these formations, but are usually localized in pools or reservoirs. Much has been written on the "anticlinal

[18] *Geological Survey of Ohio, Bulletin 1*, (1903), p. 185, and p. 201.

theory" of oil and gas. This explanation arose doubtless from the frequency with which paying wells occur in the upper parts of anticlines or near the axes of benches and terraces. In the Trenton limestone field, the wells seem to follow the axis or keep near the axis of the Cincinnati arch. Even beyond the zone of the pronounced anticlinal fold, where the formation contains only a bend or bench, paying wells are generally confined to the terrace. Elsewhere in the state, profitable drilling has disclosed a similar arching of the formations. This coincidence of paying wells and disturbed areas in the rocks has suggested the "anticlinal theory" of the occurrence of oil and gas. This theory states that since oil and gas are lighter than water, they seek the higher parts of formations which are not horizontal, the oil overlying the water and the gas capping the oil. The influence of gravity would account for such a distribution of these substances.

ORIGIN OF OIL AND GAS

These valuable resources are not found everywhere. While they occur in geological horizons that differ much in age, they do not occur in all parts of any one formation. It has been demonstrated that the oil producing area of the Trenton limestone in this state is localized. The only formation which appears to have even a general distribution of oil and gas is the Berea, but the Berea does not in all places bear these fuels in commercial quantities.

The fact that both oil and gas are usually found together, gas always with oil, implies something common in their origin. Gas sometimes occurs without oil, but in gas territories oil is occasionally found. Petroleum gives off a gas that closely resembles natural gas. Furthermore, in areas producing both, if anything unusual is found in the composition of the one, the same peculiarity generally characterizes the other also. As an illustration, the Trenton limestone produces both oil and gas in each of which there is some sulphur; but if, in a particular section, the sulphur is lacking in one, it is absent also in the other. These, and several other reasons, lead us to believe that oil and gas have a common origin.

These fuels belong to the hydrocarbon group of natural products. The principal elements in them are hydrogen and carbon. With these hydrocarbons usually occur several of their deriva-

tives. As a result, the hydrocarbons are very complex in composition. For over a century, students have been wrestling with the question of their origin, the interest usually centering about oil and gas. Two theories have been advanced; one has many advocates.

The inorganic theory. This is sometimes referred to as the chemists' theory for the origin of oil and gas. Stated briefly it is this: Steam, in the presence of carbides of iron or other metals, will form hydrocarbons. This is a laboratory demonstration. It is urged, therefore, that percolating ground water, reaching the deeper parts of the earth, produces steam which in the presence of carbides of metals forms hydrocarbons. If this theory operates in nature, both oil and gas, as well as other hydrocarbons, should be very widely distributed. The movement of ground water takes place through all rocks, those of both the continental platforms and the ocean basins. Man, much to his disappointment, has found that these fuels are localized; not many areas of any one continent have either oil or gas. The theory itself is perfectly tenable. This supposed natural plan for the origin of hydrocarbons is very similar to the artificial method of manufacturing acetylene gas. Only in the last few years has a line of investigation tended to show that hydrocarbons produced by steam and carbides of metals do differ from the hydrocarbons found in nature.[19] This difference I refer to in the next section.

The organic theory. In nearly every state, rock formations, bearing gas or petroleum, contain fossils of animals or of plants or of both. Some students urge that the hydrocarbons are formed by the slow distillation of this organic material. In the laboratory, men have made several of the hydrocarbon derivatives by distilling fish oil. Natural gas, too, frequently occurs in coal mines, known as "fire damp." Practically no oil or gas has been found in the crystalline rocks. Fossils do not occur in these rocks. Furthermore, rocks containing fossils sometimes have a very distinct petroleum odor; limestones on Kelly's Island is an example.

The organic theory, then, contemplates the slow distillation of organic remains in the rocks. Along certain tracts of the ocean borders, lakes and rivers to-day, organic remains, plant and ani-

[19] *Economic Geology*, vol. iv, (1909), pp. 626-27.

mal, become buried by sediment, and very slowly putrefy or ferment. That in this alteration gas is evolved, you have only to recall observing bubbles of gas rising to the surface of streams and of other water bodies. In 1878 Radziszewski[20] suggested that the action of bacteria on buried organic matter plays an important rôle on the development of these hydrocarbons. It is known that the decay of plant and animal tissue is due entirely to the work of these micro-organisms.

Petroleum possesses a certain optical activity which is wanting in artificially produced hydrocarbons. This activity appears to be due to certain components not found in the artificial products.

> The first main general theory, that of the inorganic origin of petroleum, has been found to be inadmissable on chemical as well as on geological grounds, since petroleums so derived are optically inactive, differing from natural oils, while the facts of the occurrence of petroleum are opposed to the theory, and allow its application only to a few occurrences of hydrocarbons in igneous rocks where these cannot have derived their bituminum from surrounding sedimentary deposits.[21]

AMOUNT OF OIL AND GAS PRODUCED

Natural gas. Between the years 1885 and 1890 Ohio ranked second in the production of natural gas, only Pennsylvania supplied more. From 1891 to 1898 the second place was taken by Indiana, Ohio ranking third. Between the years 1899 and 1903 Ohio's position was fourth, West Virginia also producing more. But from 1904 to 1908 Ohio assumed again the third rank, Indiana falling into the fourth place.

Petroleum. As an oil-producing state, Ohio has been steadily decreasing since 1900, but its output of oil up to this time was remarkable, and should be given a prominent position in any discussion of its natural resources. The appended table from the *Mineral Resources* of the U. S. Geological Survey for 1908[22] shows the production for Ohio, as well as the entire output of the country; before 1876, the oil of Ohio was included in the figure for the whole country:

[20] *Archiv. Pharm.*, 3, xiii, 455-59.
[21] Leonard V. Dalton: *Economic Geology*, iv, (1909), 630.
[22] *Ibid.*, p. 350.

(Barrels of 42 gallons)

Year	Ohio	United States	Year	Ohio	United States
1859		2,000	1884	90,081	24,218,438
1860		500,000	1885	661,580	21,858,785
1861		2,113,609	1886	1,782,970	28,064,841
1862		3,056,690	1887	5,022,632	28,283,483
1863		2,611,309	1888	10,010,868	27,612,025
1864		2,116,109	1889	12,471,466	35,163,512
1865		2,497,700	1890	16,124,656	45,823,572
1866		3,597,700	1891	17,740,301	54,292,655
1867		3,347,300	1892	16,362,921	50,509,657
1868		3,646,117	1893	16,249,769	48,431,066
1869		4,215,000	1894	16,792,154	49,344,516
1870		5,260,745	1895	19,545,233	52,892,276
1871		5,205,234	1896	23,941,169	60,960,361
1872		6,293,194	1897	21,560,515	60,475,516
1873		9,893,786	1898	18,738,708	55,364,233
1874		10,926,945	1899	21,142,108	57,070,850
1875		12,162,514	1900	22,362,730	63,362,704
1876	31,763	9,132,669	1901	21,648,083	69,389,194
1877	29,888	13,350,363	1902	21,014,231	88,766,916
1878	38,179	15,396,868	1903	20,480,286	100,461,337
1879	29,112	19,914,146	1904	18,876,631	117,080,960
1880	38,940	26,286,123	1905	16,346,660	134,717,580
1881	33,867	27,631,238	1906	14,787,763	126,493,936
1882	39,761	30,510,830	1907	12,207,448	166,095,335
1883	47,632	23,449,633	1908	10,858,797	179,572,479

CLAY

For a great many years Ohio has led the states in its clay products. The fact that a given commonwealth may market more clay products than any other does not imply a corresponding rank in raw clay. In Ohio, however, the supply of clay is very ample.

The term clay refers to deposits, which are combinations of pure kaolin with one or more of several other minerals, as silicates, oxides, hydrates, and sometimes also certain colloids or organic compounds. When rocks weather, the products are either clay or sand, or both. Silica and clay are the most common of all rock components. The purer the clay is, theoretically, the higher is its percentage of kaolin. Pure kaolin originates from the decay of feldspar which produces, upon weathering, a hydrous aluminum silicate. Between pure clay and the weathered products which are

classified as clays, there is a wide gap. This fact accounts for several varieties of clay, depending upon the percentage of given constituents.

Clay produced by the decay of crystalline or other rocks *in situ* is termed "residual." Clays which have been deposited in water, or by running water, are "sedimentary." The sedimentary clays are either unconsolidated, or are in the form of more solid rock; surface clays belong to the former, while shale represents the second class. The clays of Ohio are all sedimentary in origin; we have extensive outcrops of shale or clay. Over much of the state the glacial drift is also a source of clay; locally "bowlder" clay is well developed. Another form of glacial clay occurs in the northern counties; this was deposited in the ice-front lakes, and is called "lake" clay. Wherever rivers are making deposits, clays accumulate; the flood plains of valleys are accordingly a source of clay.

Properties of clay. The character of a clay depends upon its constituents. These are numerous, involving commonly, lime, magnesia, silica, oxides of iron, alkalies, titanic acid, alumina, organic matter, and combined water. As the per cent of a particular constituent varies, the character of the clay changes accordingly. If much iron is present, the burned clay has a stain; red brick represent a clay carrying an appreciable amount of iron oxide. If lime is in excess, it acts as a flux in burning and often gives the product a cream color. Silica makes the clay more refractory, and lowers its plasticity, while organic matter or colloids increase its plasticity. The tensil strength of clay varies from a few pounds to four hundred pounds or more per square inch. The fluxes, such as magnesia, alkalies and lime, cause the clay to fuse at lower temperatures. Thus, it is seen that products made by burning clay must vary greatly in accordance with the constituents.

In the early days of clay working, men could learn only through experimentation. The chemistry of clays was little understood. At the present time, the haphazard method of using clays will not enable the manufacturer to cope with competition. He should know the chemistry of his clays and treat them accordingly, if he is to hold a place in business.

When properly burned, many clays are very enduring. Chemical changes are introduced by burning, the manner of the burning

largely determining the change. The purpose of firing clay is to make it impervious and thus prepare it to better resist weathering. After the clay has been prepared, by grinding and mixing with water, so as to admit of molding or pressing into the form desired, this water is removed by slow drying. Next, burning removes the water of hydration, and further burning increases the hardness and density of the clay. But, to make the product enduring, the manufacturer must know at what point to stop the firing; if fired too long, the product crumbles easily. Mankind early learned the art of clay working. Burned clay products form the best evidence of prehistoric civilizations, and their success in thus treating clays is seen in the freshness of pottery that doubtless has been buried many thousand years.

Kinds of clay in Ohio. Complexity of the clayey compounds classified under the head of "clays," renders it impossible to draw fast lines between different types. In practice, a clay is named in accordance with the use made of it. The same clay, however, is sometimes used for different purposes; hence clays are not yet definitely classified on the basis of their constituents. Indeed, two clays which are quite similar in the percentage of different clay-making constituents may behave very much unlike when burned; students cannot explain just why this is. Use is the final criterion in handling a clay.

The term "fire clay" applies to those horizons that provide a clay which does not melt under a very high temperature, as perhaps 1600° C. This term is generally used for the shale horizons that often underly coal beds. This form of clay is used in making fire brick, crucibles, furnace linings, and other refractory wares. The "coal measures" supply the large percentage of our fire clays.

Another form of this resource is called "pottery" clay because it is used extensively by potteries. Pottery clays include a wide range of materials, which are varied according to the product desired. Summit County, perhaps, has the best reputation for its potter's clay.

Ohio produces large amounts of brick and tile. For this work, a great variety of clays may be used; as a result, bricks vary much in color and in other characteristics. Very many kinds of clay are used in this state for making brick and tile. The competition does not admit of freight expenses in hauling the raw material. Brick and tile plants use a clay found near the plant.

Rank of state. In 1908, Ohio supplied one-fifth of the entire output of this country's clay products; while slightly over 42 per cent of the pottery manufactured in the United States came from Ohio. This rank is due, primarily, to the fact that the state has in it the requisite raw material, otherwise the manufacturing of clay products would not have started in the state. Since these manufactories have been established, and since the state does not contain some varieties of clay required, considerable raw material is imported, part of it coming from Europe. It should be remembered, however, that the clay industry was developed, primarily, because the state has the required raw material, and its home markets needed the clay products.

As time went on, specialized products were turned out for which raw material, not provided by the state, was imported; but the business owes its thorough establishment in Ohio to the great variety and abundance of clays present.

COAL

We have many references, made by early explorers and settlers, to coal being found within the limits of Ohio. In those days, the coal was not particularly appreciated because in most areas agriculture necessitated the removal of the forests, and people accordingly burned wood, not only in the houses, but in their manufactories, for a long time. In 1810 coal was mined near Talmadge in Summit County, and by 1818 it was shipped by river boats from Akron to Cleveland. When the Ohio Canal commenced to operate, mines were opened near Massillon, making shipments to Cleveland.

The Hocking Valley coal field was used locally for domestic purposes, but the demand did not increase till about 1831, when the salt boiling industry required brisker mining; by the following year, the branch of the Ohio Canal to Nelsonville, made it possible to ship coal readily, and more extensive mining began.

By 1833, coal was being mined systematically along the Ohio even below Wheeling. Two years later a steam towboat, owned by the Pomeroy Coal Company, began delivering coal to Cincinnati. Very shortly numerous boats appeared on the river delivering coal even as far as New Orleans. At Mineral Ridge, not far from Brier Hill, coal mining commenced in 1835.

Pennsylvanian rocks of Ohio. Formerly the term Carboniferous was applied to both these rocks and the formations now included in the Mississippian period. As students learned more about this entire series, it became evident that the conditions under which the lower members were deposited differed much from later conditions. For this reason, the early part of the Carboniferous was set off into a separate period, the Mississippian, and the upper part was named the Pennsylvanian.

About ten thousand square miles of the state's surface is covered by the Pennsylvanian formations. The entire thickness of this series approximates 1600 feet. In the lower part, conglomerates and sandstones are more common. Above these, the sandstone becomes more shaly, occasionally consisting entirely of shale. Throughout the whole series, limestone beds are irregularly distributed; they are seldom very thick, usually less than a foot. Elsewhere calcareous shales and sandstone appear. Scattered through the Pennsylvanian rocks, are found twelve to fifteen seams of coal. Four or five of these are of slight importance, being very thin, and containing so much clastic material that they have no value as fuels.

While the Pennsylvanian formations appear over so wide a surface of the state and have a considerable vertical thickness, it does not follow that the given beds themselves have a corresponding horizontal area. These sediments were laid down in shallow basins, bordering the sea, and some distance inland. The arms of the sea gradually contracted, thus giving the sediments a shingled attitude. Sixteen hundred feet, which is the estimated thickness of the several beds outcropping one above the other, does not mean that difference in the altitude of the youngest and oldest rocks of the series.

Methods of mining. In the early days, the outcrops of coal along the hill slopes attracted attention. These exposures were worked by drift mining, and since, in Ohio, the coal beds have been deformed but little, these shafts did not vary much from the horizontal. The usual dip of coal beds is from twenty-five feet to thirty feet per mile. Later, vertical shafts were used. So far as recorded, the first shaft of this kind was erected at Steubenville in 1856.[23]

[23] *Geological Survey of Ohio*, vol. v, (1884), p. 323.

Men have long realized the extravagant methods of operating coal mines in Ohio, as well as in other states. Many years ago Professor Edward Orton, Sr., spoke[24] eloquently on this subject, realizing, however, that nothing could be accomplished without coöperation between the states; he showed how the loss from incomplete or reckless mining ranges sometimes as high as 25 per cent. In most cases, this is an irredeemable loss. As this fuel becomes scarcer, the methods of the earlier generation of coal operators and the conditions that accounted for their negligence and recklessness, may be cataloged among the activities of semi-barbarous men.

Centers of coal mining. There are many rock horizons in Ohio that produce coal of commercial importance. To discuss all of these would lead this chapter into needless detail. One general principle should be kept in mind. The coal areas first developed and most extensively operated are not always the best seams. Shipping facilities must control mining operations. An important factor in the cost of coal when it reaches the consumer is freight. Railroads or water routes connecting the mines and the consumer make it impossible to operate other coal areas, which do not have these shipping facilities. For this reason, the early mining operations in Ohio were partly confined to areas containing the relatively poor coal.

The Pittsburgh coal seam exists in a few counties of the state. This is the most famous horizon of coal in the Appalachian region. It is worked in Belmont more than in any other county; Jefferson perhaps ranks next. To some extent, the Pittsburgh coal is mined also in Harrison, Noble, Guernsey, Washington, Monroe, Morgan, Athens, Meigs and Gallia counties.

The Pomeroy coal, which lies from 20 to 55 feet above the Pittsburgh coal, is worked in Meigs, Gallia and Lawrence counties. While this horizon may be located in a few other counties, it is of no practical importance.

Meigs creek coal, 80 to 100 feet above the Pittsburgh, has been mined in Belmont, Harrison, Monroe, Washington, Noble and Morgan counties. It exists also in Jefferson and Guernsey, and in the latter county has been worked a little at one point.

The Clarion coal seam attains much importance in Vinton,

[24] *Geological Survey of Ohio*, vol. vii, (1893), p. 268.

Jackson, Lawrence and Scioto counties. It is found also in Gallia county, but not in a commercial thickness.

The Lower Kittaning coal is not of much importance, though it is worked at a few places. Its best development is found in Lawrence and Jackson counties. Through Vinton and Hocking, this seam is very thin, but is mined to some extent in Perry County. In Muskingum County, near Zanesville, it is worked in a small area. Through Coshocton, this seam has a slight development. It is worked in only one township, Sandy, of Tuscarawas County. In the southeastern part of Starke County, the Lower Kittaning is mined. In Columbiana, its best development is found at Leetonia where it has been used satisfactorily for coke. While occuring also in Mahoning and Jefferson counties, it is of slight importance.

From Lawrence to Columbiana County, across the state, the Middle Kittaning appears. Its most important area is the Hocking Valley field. In Muskingum County, this seam runs from 2½ to 3½ feet of good coal. One bed in Coshocton County measures five feet thick. This horizon of coal is of much less importance than the Lower Kittaning.

In one mine of Lawrence County, in Symmes township, the Upper Freeport coal appears as a four-foot seam. This horizon is not of much account anywhere across the state. Possibly, with better arrangements for shipping, its exploitation may proceed. At present, however, the best deposits are worked in the vicinity of Cambridge.

Geography of Ohio in Pennsylvanian period. By consulting a map which embraces the findings of Prof. Charles Schuchert on the question of land and water areas during the late Pennsylvanian period, in North America,[25] you will note that the western and northwestern parts of Ohio were then dry land, and that an arm of the interior sea extended eastward and northward through Kentucky and southeastern Ohio into Pennsylvania. This was a bay through which there does not appear to have been a direct movement of sea water. The fossils and plants found in the Pennsylvanian rocks indicate a variation from brackish to saline conditions in this bay.

About the margins of the ocean the land was low; extensive

[25] *Bulletin Geological Society of America,* vol. xx, (1910), plate 84.

swamps existed. The coast was not regular, but arms of the sea alternated with peninsular-like projections of the land. Between these areas of land a swamp condition existed. These flat marshes sometimes gave place to deeper water, as the coast, or as the land drainage, shifted. When this happened, vegetation was killed by the sediments brought into the water. As the shallow condition was again produced, the proper habitat for plants appeared, and the marsh condition once more prevailed. If, for any reason, the depth of water became sufficient, sea life appeared, and their calcareous remains developed limestone. Thus, we have in the rocks of this period two forms of sediment, organic and clastic; the two types of the organic, plant and animal. It should be borne in mind that on all sides of these bays or arms of the sea, this condition prevailed. Obviously, then, the area of the bay progressively decreased. The time finally came when the bay was converted into one great marsh, representing some eight thousand square miles, the area of the Pittsburgh coal seam.

The origin of coal. All are agreed on the plant origin of coal. It is further generally understood that where the coal is found now, there the plants grew. In a few cases, the coal may represent the assembling of plant remains by streams; wherever this happened, the fact is seen in the macerated condition of the plant remains.

Coal seams almost invariably overlie clay beds which contain rootlets of the plants that made the coal. This is usually termed fire clay. It probably represents the soil in which the plant growth started. Tree stumps, in an upright position, are also found associated with coal seams. Coal seams contain fossils of plants, embodying practically all parts of the organisms, leaves, fruits, bark, pith, wood, and, as seen under the microscope, spores. It is very seldom that any one plant exists so completely in the fossil form as to show all of these parts.

Many people understand that there was only one coal-making period in the earth's history. This is a mistake. During several of the geologic periods coal beds were formed. We have every reason to believe that coal beds are being formed even to-day; and this possibility aids us in unraveling the conditions that must have obtained during the Pennsylvanian period, the greatest of the coal making periods. In many parts of North America swamps with abundant vegetation may be studied now. Along the Atlan-

tic coast the combined area of swamps is approximately 20,000 square miles.[26] The everglades of Florida and the Dismal Swamp section a little north are the most extensive of these coastal swamps. In these places, vegetation is luxuriant, and as it passes from one generation to another the remains do not decay as plants decay under the atmosphere. It is a common observation that any form of wood lasts longer when kept moist or kept entirely under water. Fence posts will rot completely off above the ground and show very little decay underneath. This slow decay of plant remains is supposed to be the first stage of making coal.

Possibly another error as to the origin of coal is the prevalent idea that our coal beds represent great forests of ferns, palms, and other tropical vegetation. While vegetation of this type would furnish more quickly the amount of vegetable matter necessary to make coal, at the same time it is more probable that the lower forms of plant growth contribute more largely to the coal seams. Certain mosses which thrive at the present time in cool, moist climates appear to produce peat more rapidly than do the higher forms of plants. This is true to such an extent that it is customary to speak of peat as the product of sphagnum moss. "Under favorable conditions a foot of peat may accumulate in ten years or even less but the usual rate is probably much slower."[27] In Alaska, in many of the northern states, and through parts of Europe, and even in Ohio, peat has been forming in recent geologic times, and these swamps are still growing.

The swamp areas, bordering ocean basins, lie in tracts that are slightly above sea level. A study of the succession of deposits in the coal horizons suggests a similar relationship of the land to the sea. A delicate balance always exists between water level and swamps. While most plants that grow thus luxuriantly require permanency of moisture, at the same time a slight over-supply of moisture checks growth. Any changed relationship in the attitude of land areas to surrounding oceans is observed first along the borders. Therefore these marshy tracts may be submerged by land movement, the vegetation checked, and the swamp become a basin in which sediments are being deposited. Without

[26] N. S. Shaler, *Geographic Monographs* (1895), "Beaches and Tidal Marshes of the Atlantic Coast," p. 159.

[27] Chamberlin and Salisbury, *Geology*, vol. ii, (1906), p. 571.

any further tilting that would tend to deepen the water, the sediments in time make it sufficiently shallow for the marsh plants to again spread. The period of deep water is indicated by the clastic bed of sand or conglomerate, overlying the coal bed. The recurrence of swamp conditions is indicated by another coal seam. Again, the manner in which coal seams converge, when worked laterally, is another evidence of the alternation of swamp and sedimentation conditions.

During the Pennsylvanian period, it is supposed that the land areas in general were low, and that they were bordered by wide tracts of shallow water. The conditions of climate appear to have favored the growth of plants. That plant growth was not exactly analogous to the tropical vegetation of to-day, is inferred from a study of the coal itself and the fossils preserved in it. Outside of the Mangrove swamps of Florida, we do not, at present, have any large trees adapted to swamp habitats. The mosses and other of the lower plant forms to-day thrive best in swamp habitats.

The important factor, however, in the development of coal seams from vegetation, is the arrested decay that follows the assembling of plant remains in water or moist horizons. Beneath the water putrefaction or fermentation proceeds slowly. The oxygen is gradually given off, but the carbon is retained. The details of the change from wood to the different forms of coal are best understood by consulting the following table:[28]

	CARBON	HYDROGEN	OXYGEN	NITROGEN
1. Wood	49.66	6.21	43.03	1.1
2. Peat	59.5	5.5	33.0	2.0
3. Brown coal	68.7	5.5	25.0	0.8
4. Bituminous coal	81.2	5.5	12.5	0.8
5. Anthracite	95.0	2.5	2.5	0.0

The increasing percentage of carbon, it must be remembered, is relative. The actual amount of carbon does not gain as plants become peat, brown coal, bituminous, etc. The decrease in the amount of oxygen, through slow decay, correspondingly increases the percentage of the carbon.

Kinds of coal. The above table shows that coals are classified in accordance with their content of carbon. Sometimes coal is said to be metamorphosed wood. The conditions that bring about

[28] Chamberlin and Salisbury, *Geology*, vol. ii, (1906), p. 570.

the metamorphism, it is urged, are quite the same as those which metamorphose any other deposits, chiefly heat and pressure. This is a subject on which little is definitely known. Between peat and anthracite there is a wide gap. The difference is chemical; it appears to be largely a deoxidation process. Just the factors that contribute to this process is the part of the question on which students are not agreed. Possibly the pressure of overlying sediments indurates deposits beneath, and induces chemical changes. Possibly, accompanying this pressure, is heat which is a strong factor in the change. The slow decay of the vegetation is due to micro-organisms, which evolve chemicals, that in themselves may induce further chemical changes.

In any event, it is customary to speak of anthracite as metamorphosed bituminous coal. This explanation is given practical force because of the fact that anthracite coal is found chiefly in areas where the rocks have been very much disturbed. In eastern Pennsylvania where the strata have been sharply folded, only anthracite coal is found. In the western part of the state, where the disturbance has been slighter, the coal is bituminous. In Ohio, where there has been very little disturbance, we have only bituminous coal, and sometimes the less metamorphosed seams of poorer bituminous coal. The theory that heat appears to be connected with the change from the lower grades to anthracite coal is further strengthened by a study of coal deposits in New Mexico, where portions of bituminous beds next to igneous intrusions have been changed to anthracite.

Rank of state. Ohio is one of the older states in the production of coal. It has long maintained a prominent position, and during the year 1908 ranked fourth in both tonnage and value. Many of the coal seams in Ohio are not as valuable as others. It is to be hoped that as men learn more about the nature of coal deposits and their adaptation to different uses, the lower grades of coal may be found of increasing commercial importance. Only in the last few years have we begun to attack the question of coal scientifically. Men learned early that all coals would not coke, but they did not ask themselves why; experiment eliminated the poorer coking coals. Sometimes the efficiency of a coal is very much lowered by impurities acquired in process of mining; these, it has been found, may be partly eliminated by washing. It has been learned, furthermore, that furnaces and other arrangements for using the

fuel must be varied to suit types of coal; a particular coal may have low efficiency in a furnace which will get a much higher amount of heat out of another coal to which it is adapted. The laboratory work now under way by the federal government, as well as by some of the state institutions, will add materially to the importance of the lower grade coals.

GLACIATION IN OHIO

INTRODUCTION

In many of the northern states and much of Canada, one cannot get away from the evidences of glaciation. It has been estimated that the area of the continental glacier was 4,000,000 square miles. No page in the geological chapter is plainer, yet students were very slow in reading it correctly. Of all the evidence, the most striking, perhaps, is the presence, in an area of organic and clastic rocks only, of scattered bowlders of crystalline rocks. We sometimes call these "erratics," sometimes "nigger heads." Early the question was asked, how did they come here? But for a long time the question was not correctly answered. Most students who gave the matter any attention said that they were dropped from the bottom of icebergs that floated about over the lands when covered by floods, possibly the floods of Noah's deluge. Then other curious phenomena were noted: Broad rock surfaces were seen to be striated and grooved. At first it was said that these markings only showed where icebergs, shod with stones, had bumped along across the shallow parts of the seas. But how could this make the markings so parallel, it was asked, and why did the striae always have such a uniform direction? These were indeed puzzling questions, but not too severe for those of much orthodoxy and little reason. Again, men noted mounds of heterogeneous material, large and small stones, stones of many varieties. These tumuli were sometimes in the lower places, often on valley walls, and sometimes on the highlands between valleys. Streams, it was

well understood, deposited gravel and silt, which would be found only where streams had been..

In time all these puzzling observations came to be understood. Now, within the area that was glaciated one seldom meets a citizen who has not some knowledge of the glacial period.

Margin of the ice sheet. Nearly three-fourths of Ohio was covered by the ice sheet. The front of the ice coincided roughly with the rugged topography of the coal regions. On the eastern border of the state, the glaciated area terminates about ten miles north of East Liverpool. Its margin runs almost directly west to Canton; thence it has a southwest direction to Millersburg, in Holmes County. From Millersburg, the ice began to turn more nearly west, to approximately the eastern border of Knox County. From this point, for several miles, the general front of the glaciated area has a north-south direction. But upon entering Perry County, it again bears to the southwest, crossing the Scioto River near Chillicothe; from Chillicothe the same general direction continues to the Ohio river, in Brown County. From this point westward, nearly to Cincinnati, it reaches a few miles into the area of Kentucky.

This glacial boundary in Ohio is but a segment of the margin of the great ice sheet that covered so much of North America. In the western part of the Mississippi basin, the general front had a northwest-southeast direction, except near the Rocky Mountains, where it trended more nearly east-west. About one-third of Montana was ice-covered. The southwestern corner of North Dakota was beyond the ice sheet, and the western half of South Dakota was not glaciated. From this point, the front of the glacier bore almost directly south, covering the eastern end of Nebraska, then turning to the east; only a small area of the northeast corner of Kansas was glaciated; thence the ice margin bore slightly south of east, crossing the Mississippi River a few miles north of Cairo, Ill. In southern Indiana, a triangular shaped area, its base following the Ohio River north to Madison, was not glaciated; a short distance north of Madison the ice crossed the river; thence, its front trended slightly north to the vicinity of Cincinnati.

The northwest corner of Pennsylvania is also included in the glaciated area, the ice-front passing northeastward into New York State; it shortly bears southward again, leaving New York

State near Olean. From this point, towards the Atlantic, the ice margin had a southeasterly course, crossing the Susquehanna River a few miles south of Wilkesbarre; thence the ice trended more nearly east. The Delaware River was crossed in the vicinity of Easton, Pa.; and the ice-front bore eastward from New Jersey, just south of Staten Island. A sharp moraine extends the entire length of Long Island, but the ice sheet may have reached farther south. From this point eastward, the margin of the glacier cannot be determined. It is certain that all of New England was glaciated, and it is thought either that the ice extended into the area where the Atlantic now is, or that the shallower part of the ocean, bordering New England, was then land on which the ice sheet terminated.

Whether all of British America was covered by this same great ice sheet, is not definitely known. It is supposed that Labrador was entirely glaciated, and that the area from Hudson Bay westward into the Mackenzie valley was also covered with ice. But, west of this river valley, it appears that the ice belonged to the high altitudes of the Rocky Mountains, that is, the Rocky Mountains in British America were covered by a different sheet, a sheet of local origin. All of the other parts discussed were covered by a continuous ice sheet.

How this ice was formed. We are acquainted with the ice that forms on the surface of our streams and lakes, but glacier ice did not originate in this way. An appreciable thickness of water may be frozen in a short time. Such ice differs very much from glacier ice. No one has demonstrated exactly how glacier ice is made; laboratory facilities cannot be arranged to give an object lesson in this. Snow may be turned into a form of ice by pressure; a mass of snow, a névé field, through continuous accessions, will develop sufficient pressure, by its own weight, to change the snow crystals into granules. This first change produces what is called granular névé. In the gathering areas of the Alpine glaciers, névé fields have been studied. Further pressure through increasing weight changes this granular névé into glacier granules, small round bodies of ice. Later these granules form glacier ice.

It is impossible to reasonably approximate the weight or the volume of the ice sheet that covered so large a portion of North America. It is known that high mountains in New England were completely covered; that southward of the broad basins now

occupied by the Great Lakes the ice pushed far into the Allegheny plateau; and that in the Mississippi valley, where no great heights exist, it expanded so far to the south that its mass must have been great. Men have attempted to estimate the thickness of this sheet in particular places by studying the slope of the ice front. It has been found that where the margin of the ice front was registered, by accumulations of drift against the sides of the valley, for example, it had a certain decline. By carrying this same slope northward, one gets a suggestion, at least, of the thickness at any given distance to the north. Such a study has assigned astounding depths to the ice, so great that one concludes that this method is not reliable. The fact that the ice sheet had a certain length in the Mississippi valley, and that it moved outward from a given place, would warrant the conclusion of great thickness over part of the area beween these termini.

How then was so much ice made? This is a question on which much has been written. The simplest explanation assumes a heavy and regular annual snowfall, with little or no melting. If this form of precipitation were to continue a sufficient length of time, and little of it were to be melted, eventually an ice sheet sufficiently great to cover any continent might result. But such an explanation hypothecates a condition which, we all believe, never existed. We have to-day some small areas of continuous ice: one about the south pole, the other covering most of Greenland. In both of these areas there is neither continuous snowfall nor an absence of melting. Man knows of no altitude so high that the ice which forms there does not suffer from some melting. It wastes even when the temperature is continuously below zero. The essential prerequisite for the development of ice fields is that precipitation, in the form of snow, should exceed the wastage. However small the increment left over from each warm season, if this relationship of snowfall and melting continues long enough, an ice sheet will result.

A study of the glaciated parts of North America, omitting the Rocky Mountain region, points to two centers in Canada, away from which the ice moved. One center lies east of Hudson bay, in Labrador; the other is west of Hudson bay, in the Keewatin district. In these areas, for perhaps thousands of years, the prevalent form of precipitation was snow; in both, at first, only slight bodies of snow endured from one year to another. Gradually the

mass of snow increased, and by its own pressure the lower parts were changed to granular névé. With the increments of later seasons, granular ice was formed; with continued snowfall, this moved laterally as glacier ice.

How glacier ice moves. Should you visit a valley glacier of Switzerland you would find in its névé field evidences of growth, while at the lower terminus of the glacier you would see evidences of wastage. Between these two points the valleys generally have a marked slope. The question of motion does not here appear to be complex. Ice, we all know, is not a solid; a block of it, when supported only at the ends, sags in the middle of its own weight. The movement of these valley glaciers is so obvious and so natural that they are sometimes called ice rivers. It is immaterial how deep they may be; a tongue of ice in a valley, which slopes away from a mountainous area, should move.

But when we think of a great continental glacier, covering thoussands of square miles in one continuous sheet, we cannot find the same reasons for motion. Motion in Alpine glaciers appears to be largely a matter of gravity, and yet the process is not the same as the motion of a cable, which is being fed through an inclined conduit, or what occurs at the lower end of an inclined plane, already filled with ice blocks, when we add another block to the upper end. While there is movement in these Alpine glaciers and in the ice sheets, they do not appear to move as a unit; the motion is not so simple. The gathering or dispersion center of an ice sheet is its place of growth, the margin, its place of decay. When the margin remains stationary, as well as when it advances, a forward motion must prevail in the ice, back to the dispersion area, and this in spite of a prevailing temperature below the melting point.

Ice is a mineral; when forming, the molecules arrange themselves according to the hexagonal system of crystals. When snowflakes are piled up, these crystals are bent of their own weight, crowded together, interlocked, and they suffer some melting. It is thus that the structure of névé becomes granular, and the individual granules grow. By experimentation, it has been proved that these granules grow under all conditions of temperature. We all know that in crystal growth great pressure is exerted; thus, jars are broken when water freezes in them. The expansion causes pressure, and because of pressure, great tension must exist in every ice area. Physicists teach us that heat is an accompaniment

of pressure. It has been determined that when the pressure evolved in a growing mass of ice equals one atmosphere, the heat equivalent is to 0.0075° C. Students now believe that in masses of ice, either of the Alpine or Continental glacier type, there is constant melting and almost immediate refrigeration of tiny particles of ice and water, resulting possibly from pressure and constant tension. If this is true, the units, either crystals or granules, in an ice sheet must be almost constantly in motion.

At the heads of glaciers, where motion is initiated, there may be great downward pressure, but not vigorous thrusts from behind, and probably only moderate thrusts developed within the body itself. There seems, therefore, no escape from the conclusion that the primal cause of glacial motion is one which may operate even under the relatively low temperatures, the relatively dry conditions, and the relatively granular textures which affect the heads of glaciers. These considerations lead to the view that movement takes place by the minute individual movements of the grains upon one another. While they are in the spheroidal form, as in the névé, this would not seem to be at all difficult. They may rotate and slide over each other as the weight of the snow increases; but as they become interlocked by growth, both rotation and sliding must apparently encounter more resistance. The amount of rotary motion required of an individual granule is, however, surprisingly small, and the meltings and refreezings incident to shifting pressures and tensions, and to the growth of the granules, seem adequate to meet the requirements. In order to account for a movement of three feet per day in a glacier six miles long, the mean motion of the average granule relative to its neighbor would be, roundly, $\frac{1}{10000}$ of its own diameter per day, or one diameter in 10,000 days; in other words, it would change its relation to its neighbors to the extent of its diameter in about thirty years. A change of so great slowness under the conditions of granular alteration can scarcely be thought incredible, or even improbable, in spite of the interlocking which the granules may develop. The movement is supposed to be permitted chiefly by the temporary passage of minute portions of the granules into the fluid form at the points of greatest compression, the transfer of the moisture to adjoining points, and its resolidification. The points of greatest compression are obviously just those whose yielding most promotes motion, and a successive yielding of the points that come in succession to oppose motion most (and thus to receive the greatest stresses) permits continuous motion. It is merely necessary to assume that the gravity of the accumulated mass is sufficient to produce the minute temporary liquefaction at the points of greatest stress, the result being accomplished not so much by the lowering of the melting-point as by the development of heat by pressure.

This conception of glacial "flowage" involves only the momentary liquefaction of minute portions of the mass, while the ice as a whole

remains rigid, as its crystalline nature requires. Instead of assigning a slow viscous fluidity, like that of asphalt, to the whole mass, which seems inconsistent with its crystalline character, it assigns a free fluidity to a succession of particles that form only a minute fraction of the whole at any instant.

This conception is consistent with the retention of the granular condition of the ice, with the heterogeneous (in the main) orientation of the crystals, with the rigidity and brittleness of the ice, and with its strictly crystalline character, a character which a viscous liquid does not possess, however much its high viscosity may make it resemble a rigid body.[1]

THE WORK DONE BY GLACIERS

There are two methods of determining the work done by the continental glacier. We may study ice masses in existence today. Glaciers of the Alpine type are found on every continent. Greenland, an island 512,000 square miles in area, is almost entirely covered with ice; this is an ice cap, and approximates a continental glacier. In Antarctica there exist extensive ice areas, while in Alaska there are many splendid examples of the Piedmont or Malaspina type of Glacier. Relative to their size, these glaciers give many suggestions of the work that the continental glacier, such as once covered our part of North America, must have done. Another method of unraveling the activities of the ancient ice sheet is to study the evidences which it left. It made great accumulations of drift, it has worn and polished rock surfaces, has carved deeply elsewhere into the rock, has silted up river valleys leading away from the glaciated areas, and has produced complex soils, by bringing together material from distant parts.

The glaciers now in action are tearing away and building up. So far as we can determine, the glaciers of the past did the same. Glacial work consists of erosion, transportation and deposition. Sometimes these factors appear to be of equal weight. In other areas, one or the other is in the ascendant. Naturally erosion and deposition are opposed, and cannot be in operation in the same place at the same time.

EROSION BY GLACIERS

A country once glaciated always bears the scars of icework. No other natural agencies degrade and aggrade just as glaciers do.

[1] Chamberlin and Salisbury, *Geology*, vol. i, (1905), pp. 299–301.

Rivers cut rock, heat and cold crumble it, chemicals disintegrate it, tool-laden winds scour it, lightning may rive it, and earthquakes disrupt it, but never is the effect that of glacial action.

Contrast between glaciated and unglaciated regions. In countries where glaciers have never scoured, we find the bed rock covered by a mantle of residual soil, the thickness of which depends upon a great many conditions. But where a glacier has moved over the area, this residual material is largely, if not entirely, wanting. Valleys in an unglaciated region are narrow or flat, according to their age. When narrow, their cross-section is like the letter V; when broadened by age, the sides of the V are more flattened. Broad, unglaciated valleys have smooth sides, the slopes are continuous and uninterrupted; a view through such a valley shows interlocking spurs, the inheritance of a natural tendency of streams to swing. In an unglaciated area the surface reflects the texture and attitude of the rocks; shoulders and escarpments mark the harder horizons. From cliffs of a hard ledge, overlying a softer horizon, continued weathering removes great blocks which come to a temporary position of rest on the slope below. Accentuated weathering along closely assembled joint planes carves the ledges into columns and pillars, which sometimes are isolated as great stacks and spires. The hills and mountains of unglaciated countries have uniform outlines, except when folding has tilted the layers; then the harder beds break the otherwise even slopes.

Should such an area as the one just described be glaciated, either the valleys would be buried, or their cross sections would be so altered that they would resemble more nearly the letter U. If the valleys were transverse to the direction of glacial motion, in all probability they would be largely filled with drift; if parallel to glacial motion, they would be plowed out and their profiles would be changed. The ice, feeding through these valleys, would wear off the ends of the interlocking spurs. Instead of having continuous slopes, near the axis of the valley the slope would be oversteepened, while farther up, it might be made irregular by deposits of drift. The cliffs and other evidences of differential rock weathering would be partly or entirely obliterated through glacial scouring and plucking. The remnants of weathering, such as spires, stacks, and detached blocks on slopes, would be removed. The hills would no longer have uniform outlines, but would be

worn away more on the stoss side, the side approached by the ice. Mountain slopes would be broken through localized ice action, and the mountain tops would be rounded. There would be very little residual soil left. Rock areas, where not covered by drift, may show the effects of glacial scouring, either in smoothed, striated, or grooved surfaces.

Tools of glacier ice. Clear ice never abrades rock surfaces, any more than water, without tools, erodes the beds of rivers. But glacier ice acquires tools readily. As it first moves into a country, it finds a great mass of residual and loose rock. This material is gradually worked into the ice and held as tools, to rasp all surfaces against which the ice moves. After the residual soil has been removed, the acquirement of a further load is an easy task. Man has never yet gone so deep in the earth that he has not found the rocks broken by joints and faults. These divisions make it easier for rivers and ice to remove blocks. This is especially true when ice moves through a valley or around hills and mountains. The great bowlders, sometimes weighing many tons, scattered over the states, were brought from areas north, probably from the slopes of valleys or the sides of hills.

Furthermore, effectiveness of glacial erosion depends directly on the hardness of its tools. Some rocks are so soft that they can accomplish very little abrasion, even against the same kind of rock. The size of the tool is of slight importance. A grain of sand, will probably wear rock beneath the glacier more than would a slab of shale weighing many pounds, because quartz is very hard. The erosion accomplished by a glacier is not entirely on its bed. The rock which is taken into the basal parts of a glacier is raised from one level to another, through the buckling and shearing of the ice; the material may ascend even to the surface of the glacier. Consequently much mutual attrition of block on block tends to wear the tools in transit. Streams issuing from glaciers bear heavy loads of exceedingly fine material, partly produced by this mutual attrition.

Evidences of erosion. The most universally convincing proof of the power of glacier ice to wear rock is seen in a surface that bears striae, grooves, or gouges. Such a surface merely shows a stage in glacial eroson. It is by the continuous removal of the rock, in registering even delicate scratches upon it, that hundreds of feet of solid rock have been gradually rasped away from the

bottoms of valleys in some localities. Sometimes, along the sides of a valley, a block will be plucked bodily; but the slow scouring and rasping process, such work as the glacier did last on a striated surface, is the more usual method of wearing away rock.

The fiords of Alaska and Norway, the U-shaped valleys of Switzerland, the rock basins now holding lakes in England and Scotland, the over-deepened valleys in the Finger Lake region of New York, the cirques and amphitheaters of all glaciated mountainous areas, show the competency of ice to erode rock. There may be a lack of agreement among students as to just how fiords and rock basins were produced. In the studies of Gilbert in Alaska, of Penck, Brückner, and Davis in the Swiss region, of Reusch in Scandinavia, of Marr in England and Scotland, of King and Atwood in the Rockies, of Chamberlin and Salisbury in Greenland, and of Tarr and others in central New York, we have an array of evidence that takes the question of glacial erosion out of court. It is no longer a discussed point.

The conditions that obtained in the regions where active ice can now be studied are not necessarily identical with the erosion processes of the ice sheet in North America. The closest example, perhaps, is found in Greenland, where a valley leading to tide level now bears a tongue of ice, behind which is a large area of ice whose forward movement is concentrated on this one valley as an outlet; erosion consequently is vigorous. In all of our over-deepened valleys, fiords and basins, it is probable that ice action was similarly concentrated. Such a tongue of ice, shod with tools, slowly rasping the bottom and the lower side walls of the valley, and continuing in action through many centuries or perhaps thousands of years, did not accomplish anything astounding, in wearing away the rock many hundred feet. In addition to lowering the bottom of the valley, its walls were cut back, thus changing its cross-section to a broad U. Tributary streams that formerly met the major stream of the valley at grade were left hanging several hundred feet. "The hanging valley is especially significant in two lines of physiographic interpretation. It is a conspicuous earmark of the former presence of glaciers; and it helps to a conception of the magnitude of the Pleistocene glacial erosion."[2]

[2] Harriman Alaskan Expedition, vol. iii, (1904), *Glaciers and Glaciation*, page 115.

DEPOSITION BY GLACIERS

Glacial deposits are always heterogeneous in material, and usually so in texture and structure. The word "drift" includes all débris transported and deposited by glaciers or streams issuing from glaciers. "Till" refers to the deposits made directly from the ice. The material assorted by glacial waters is called "modified drift." The designation "drift," therefore, includes the other two.

The simplest condition of glacial accumulations. The earliest terms used in reference to the accumulations of glaciers referred particularly to valley glaciers. Valley glaciers carry along their sides much material rasped from the walls of the valley. At their ends, where melting takes place, the débris not carried away by the outwash stream accumulates, forming a "terminal moraine." The deposits that gather along the sides or margin of a glacier are called "lateral moraines." When one valley is tributary to another and a glacier occupies each, the two lateral moraines, below the point of coalescence, unite, forming in the single glacier stream a "medial moraine." These three designations for moraines are the earliest and best fixed in the literature. Unfortunately, their limited use has given rise to much misconception in America, where only a fraction of the ice deposits was made by valley glaciers.

The more complex conditions of a continental ice sheet. The deposits made by a continental glacier are of a very complex origin. The drift which we study to-day, in most of the states, was left by the retreating ice sheet. This retreat was slow. All the conditions of melting and drainage along its front merely repeated conditions that obtained while the ice sheet was expanding. If, after the continental glacier had attained its maximum growth, the conditions that induced glaciation had suddenly ceased to operate, and all of the ice had melted in situ, as an exposed block would melt on the sidewalk, the glacial deposits made would be simple. A terminal moraine accumulated as often as the advancing ice sheet held a stationary position for any great length of time; when the glacier advanced further, this moraine was subject to ice erosion. For this reason, much of the moranic material, which accumulated as the ice sheet was spreading out over the country, was altered. For this reason, the drift

that we study to-day represents for the most part the deposits made by the retreating ice sheet.

Definite ice halts are registered by bands of thickened drift; the country between such morainic bands also bears drift called "ground moraine," The bands of drift are built up where ice wastage and ice feeding are approximately equal. If, in a year, the front of the glacier is wasted 1000 feet, and the onward movement of the ice sheet during this time is also 1000 feet, its margin remains stationary, and the débris in that thousand feet of wasted ice is deposited at the margin. If the feeding of the ice is slightly less than the wastage, the margin retreats slowly and the débris is accumulated in a wider ridge or band. We sometimes have morainic bands several miles wide. These represent marked wastage of the ice accompanied by almost as active feeding.

It has been established that a continuous advance did not characterize the precessional movement of the glacier; nor did a constant retreat mark its recession; instead, oscillations took place at many points along the margin. For several seasons the front of the ice may have held a nearly constant position; then, during succeeding years, the ice growth being greater than the ice decay, the margin advanced, riding over and eroding deposits just made; or, the wastage being much in excess of the feeding, a corresponding retreat resulted.

Terminal moraines, retreatal moraines, morainic loops. The farthest advance of any particular ice sheet is marked by the terminal moraine of that epoch. Other positions of the margin, lying iceward of this extreme position, are marked by "retreatal" moraines. All bands of drift between the terminal moraine and the dispersion centers of the ice are retreatal moraines. Small basins and valleys were occupied by lobes and tongues of ice. Along the front and sides of these lobes and tongues débris accumulated, forming morainic loops. Morainic loops are details of retreatal and terminal moraines.

The margin of a continental glacier is always irregular, if there is any appreciable relief in the country which it covers. The movement of the glacier is retarded by increasing altitudes; it moves onward freely into valleys or basins of lower altitudes. Our continental glacier, extending as it did quite across the whole continent, met a great variety of relief. Through the basin of the Mississippi, the ice advanced most easily and extended farthest.

The Appalachian mountains and bordering Allegheny plateau impeded its progress; consequently, the margin of the ice eastward of the axis of the Mississippi valley had a northward trend. These large physiographic provinces gave the glacier its general outline, while local topography caused the minor irregularities of the margin. Parts of the Allegheny plateau are dissected by north-south valleys. This condition is noted in central and western New York. These valleys produced in the ice-front a very dentate outline. During both the progress and the retreat of the glacier, each valley was occupied by a tongue extending several miles beyond the main ice mass. The plateau parts of Ohio are also irregular in relief. Where its valleys were coincident with the direction of ice motion, tongues and lobes extended into them, and often moved many miles beyond the ice sheet proper. The Grand River valley, the Scioto, and the Miami, each caused a lobation in the ice front. Slighter valleys, contiguous to these, caused minor details along the margin of these lobes. The retreatal moraines and smaller loops enable us now to decipher the value of this topographic factor in reconstructing the outline of the ice-front.

Glacial deposits in valleys. Valleys contiguous to the ice front always carried a great supply of water. If the valley sloped away from the ice, this water flowed off. If the valley sloped towards the ice, the water gathered, forming a lake which continued to deepen till an overflow somewhere about the border of the valley was discovered. Under the former condition, the valleys now usually bear heavy deposits of outwash material, which has been progressively terraced during and since glacial times.

When a speedy retreat followed a stationary position, maintained a long time by the ice, morainic terraces were left along the valley slopes. Where, on account of minor irregularities in the valley wall, local bodies of water gathered, the drift accumulating in them was prevailingly washed and stratified. When gravel and sand prevail in these deposits they are called "kame terraces."

If, in a valley, the ice became less active and some portion of it was left stagnant, later stream deposits might completely bury all or part of it; such a buried block of ice would melt slowly; possibly hundreds of years elapsed before all had disappeared. The position of a detached mass of ice is to-day indicated by a basin called a "kettle hole;" when containing water, a "kettle lake." Modified drift, and, less frequently, kettle lakes, characterize kame areas.

Whenever a tongue of ice stood for a long time at a given point in a valley, its sides and front were marked by a morainic loop. The streams issuing down through the valley from this position were heavily laden, and in consequence aggraded the valley floor for several miles beyond. The washed deposits thus accumulated down stream from a morainic loop are called "valley trains."

Outwash plains. The intervalley portions of retreatal moraines are often bordered by gradually sloping bands of gravels and sand called "outwash plains." The material of these plains was deposited by streams or sheets of water issuing from the ice-front. Local irregularities of relief in this intervalley area introduced corresponding irregularities in the shapes of these outwash plains. The genesis of valley trains and outwash plains is practically the same, except that the former deposits are confined laterally.

Eskers. Sometimes in the thinner areas, near the front of the ice sheet, surface water may be directed towards a crack or opening in the ice, and then flow along beneath the glacier to its margin. This condition could not exist if the ice were very active; it obtains only in stagnant or semi-stagnant ice areas. Streams gathering on the surface and flowing into a depression to the bottom of the glacier carry with them much débris. They also continue to transport material as they flow beneath the glacier. In reference to carrying a load, subglacial streams behave just as do surface rivers; they aggrade and erode. As they aggrade their beds, the stream itself is lifted against the arch above and tends to melt the ice further. This process continuing, the channel becomes more aggraded, and the size of the arch gradually grows. At the mouth of the channel, that is, at the glacier margin, finer materials, which the stream was able to carry through, are deposited. Sub-glacial streams, in one respect, differ from surface rivers; they may flow up hill. This is possible through hydrostatic pressure. Water accumulating on and beneath the ice may form a reservoir of sufficient volume to give pressure that will lift a stream over a considerable altitude.

The courses of these streams are indicated to-day by the long sinuous ridges of washed drift. The outline of these ridges shows the shape of the ice arch that once was above them. Their vertical range defines the irregular grade of the sub-glacial stream. Ridges of this origin are called "eskers." They usually have a serpentine course; and because they consist almost entirely of

washed deposits, they were formerly called "serpentine kames." In general shape and sometimes in position, they resemble morainic loops, but can be easily distinguished by examining their material.

Valleys leading away from the ice. In some parts of the country, ice-borne material is found hundreds of miles south of the margin of the continental glacier. The Delaware, the Susquehanna, and the Ohio rivers carried outwash from the ice sheet, far to the south. In this state, the Muskingum and its various tributary valleys, the Scioto, the Hocking, and the Miami river valleys, are flood-plained and terraced by waters that issued from the glacier. The abundance of this outwash, and its great distance from the margin of the ice, furnish convincing proof of the turbulent condition of streams that flowed from the ice sheet.

Lake deposits. The drainage from glaciers does not always flow away freely. When the land slopes towards the ice front, the water accumulates. If the area is a plain, the resulting lake will be long, with its greater axis parallel to the ice margin; if the area is a valley, this axis will be transverse to the ice margin. The depth of such a lake depends upon the altitude of the outlet which eventually its waters will find. The present-day evidences of these former lakes is dependent upon their duration; the longer a lake stood at a particular level, the more sharply developed became its shorelines. The duration of ice-front lakes is contingent on the time during which the ice held its stationary position. Some lakes that bordered the front of the recessional ice must have endured for many centuries; others were relatively evanescent.

In nearly all respects, these ice-front lakes were like the lakes of today. Rivers flowed into them, bays varied their outlines, winds made waves on their surface, currents doubtless existed, just as in the Great Lakes. Cliffs were cut by wave work, and beaches constructed. At the mouths of rivers, deposits accumulated as deltas. Spits, bars and cusps varied the shoreline. Away from the shore, fine material was deposited as lake clay. But, in these lakes, the quantity of clay was greater than in non-glacial lakes; along the entire margin of the ice, which always formed a part of the shoreline, débris gathered from the wasting glacier; this contained much fine clay, which was disseminated in suspension through the lake, gradually settling to the bottom. For this reason, clay is found more commonly on the beds of glacial lakes.

These lake deposits have been exposed to weathering since glacial times. This interval is variously estimated as from ten to forty thousand years. However long it really is, weathering has spared to an amazing degree the work of the glacial lakes. Their old shorelines, with interesting details of structure, in addition to the cliffs cut in enduring rock, stand out conspicuously to-day. Their deltas, creased, to be sure , by gulleys and streams during the post-glacial time, still bear their original outlines. The locally thick mantle of lake clays has sometimes slumped into corrugated ridges, but is always easily recognized. The islands that often dotted the ice-front lakes are encircled by cliffs and beaches; those near the shore were tied by bars, which cannot escape one's attention even to-day. Their overflow channels now are frequently only fossil river-valleys. No phase of glacial history inspires greater zest in investigation.

EFFECTS OF GLACIAL ACTION

Usually there is no difficulty in distinguishing a glaciated from a non-glaciated region. Normally, a country's surface is made irregular by rivers and other weathering agents; but while that country is buried beneath an ice sheet, these agencies cease to act. The rasping and aggrading effects of a continental glacier tend to decrease the irregularities of pre-glacial topography. Eminences are smoothed out or rounded. Broken slopes are usually made more regular. Minor depressions are frequently filled with débris. Thus, the usual effect of glaciation is to decrease surface irregularity. At the same time, glaciers often increase the relief. The extent of smoothing, and of giving added relief, depends somewhat on the rock texture and structure of the region. Easily eroded rocks suffer most from glacial action. When hard rocks do not exist in the area itself, or in its immediate environment, the glacier is not supplied with effective tools for erosion.

When relief is increased. Glacier ice cuts deep only when its erosive powers are concentrated. Whether a given area under glaciation will come out with increased or diminished relief, therefore, depends upon its topography preceding glaciation. If it already bears a pattern into which the ice fits as it moves, the relief of that pattern will be increased. Such is the case when the country has valleys trending in the direction of the ice motion.

Glacial topography. The deposits made by an ice sheet account for much of the resulting relief. Morainic bands, which mark relatively stationary positions of the ice margin, almost invariably are irregular in surface. This irregularity is partially genetic, more debris being deposited at one point than another, and is sometimes due to the erosion of waters flowing away from the ice margin. A morainic surface is always slightly irregular, and frequently has sharp relief. In valleys, the loops of drift generally form ridges. These ridges vary from a few feet to over one hundred feet in height.

The esker is another ridge which makes glacial topography irregular; as already discussed, eskers do not always follow valleys or in their direction show complete control by preëxisting topography.

Kames are mounds of prevailingly stratified deposits; these mounds frequently have intervening depressions, sometimes containing water, called "kettle lakes." Kames from 100 to 200 feet in height are not uncommon in connection with morainic bands. The size of kettle lakes and of depressions in drift areas varies much. These depressions are sometimes due to detached blocks of ice being buried beneath accumulating drift. Ice thus covered decayed very slowly. The larger the block, the larger the resulting depression. Even if no deposits were made about the block, as it was covered, a slight basin would mark its position; as it decayed much of the débris in the ice would slump down the sides of the mass, coming to rest on the plain beneath; the quantity of this débris would decrease as the block grew smaller, hence a depression would be formed. Sometimes large portions of a valley tongue, the glacier being stagnant, have been thus buried. No doubt many centuries passed before such a large mass of ice entirely disappeared. In Alaska are forest trees, growing on a soil horizon that accumulated over ice plains thus protected from decay; plants took root, and eventually trees spread over the area. No one can tell how long such a buried mass of ice may endure.

Drainage changes. The preglacial stream pattern is sometimes altered through glaciation. Fewer changes result (1) when the land drains away from the ice, but modifications are possible, (2) when the rivers of the area flow towards the ice margin. Drainage change is also possible, and no doubt often has resulted, (3) when the preglacial streams had a course parallel to the ice margin.

We know very little about the actual methods of glacial erosion. A valley may to-day bear a glacier, and in the part of the valley from which the glacier has retreated the evidence of erosion may be obvious. But no one can tell just what is going on beneath the tongue of ice. All infer that the basal part of the ice is shod with stones which, by the weight of the ice above, are held against the rock beneath, and, as the glacier slowly moves, this bed rock is worn. Probably our chief stumbling block in appreciating the erosion accomplished by glaciers is our difficulty in grasping the time involved. The history of mankind is so short that man's imagination fails him in conceiving geologic time. Primitive man shaped his tools by wearing a softer rock against a harder. Even two rocks of the same hardness may be made to wear each other out. A tiny scratch in a slab of rock removes a measurable amount of material. The entire mass of the rock is only a multiple of that quantity removed. Given time enough for sufficient repetitions of the scratch, and the rock may be worn away. No one hesitates to grant a glacial period tens of thousands of years duration. Many do not hesitate to make it hundreds of thousands of years. Even the more conservative estimate would account for such glacial erosion as we have studied, provided the ice were continuously laden with tools. It is the tongue of ice leading ahead of the main mass, through valleys, that does the great erosive work. Towards the axes of such valleys the weight of the ice trends. The depth of the valley insures this weight. The valley walls supply tools which, added to the rocks already in the ice, insure erosion. Consequently, the rock relief of the region must be increased, if the region preglacially had valleys trending in the direction of the ice motion.

When relief is decreased. The removal of minor irregularities by the general erosion of an ice sheet, to that degree decreases relief. The basins and valleys existing preglacially in the area measure its maximum relief. If these depressions are transverse to the direction of ice motion, they will not be deepened; more often they will be shallowed through the accumulation of glacial débris. The orientation of the lines of greatest relief decides whether that relief will be increased or decreased through glaciation. It is possible that the irregularity of glacial deposits, as discussed in the next section, may have greater relief than the area had originally.

Since the streams that flow from a glacier usually bear a load, one can understand how, under the first of these conditions, the valleys would be silted up with outwash material. Flood plains thus are quickly developed. If the valley concerned was already in old age, the mass of this material accumulating might locally reduce the grade of the valley floor to the extent of ponding some of its drainage. Minor changes have been thus induced.

Under the second condition, lakes are always formed in the valleys. The levels of these lakes rise until they find an overflow. If the overflow channel is in unconsolidated material or in very soft rock, it may be so cut down as to permanently change the course of the drainage.

In the third condition, the ice at some point moves across the valley or basin of a river, whose general course is parallel to the ice margin. When this happens, the upstream part of the basin is ponded, and, if the ice occupying it rises higher than the lowest point on the basin's rim, the ponded water will escape at that point; but if the ice does not thus completely block the valley, the ponded water up stream will flow over the ice or between it and the wall of the valley. In the former case, if this new channel continues in use long enough, it may become the permanent course for the drainage of that part of the original valley.

In the glaciated area, many drainage changes have been attributed to ice. Later investigation of some of these reversals appears to throw doubt on the former explanation. Evidence has been found, showing that the reversals had been accomplished before the glacial period. In another section, I consider some of these cases.

CAUSE OF GLACIAL PERIOD

Many explanations have been offered for the extensive glaciation of certain parts of the continents. Most theorists have proceeded from observations made in our temperate regions. Above the snow line in mountains, snow accumulates in accordance with the precipitation. With an increase of snowfall through several succeeding years, the snow line is lowered. Under an equal period of diminished precipitation, the altitude of the snow line rises. It is urged, therefore, that a prevalence through centuries of the former conditions would extend ice fields down the slopes of the mountains and into the adjacent plains.

Former higher altitude of continent. Consequently, the explanation most universally offered for a glacial period rests upon a high altitude of the continent. Those who advocate this urge that, preceding the Pleistocene period, northern North America must have had a much greater altitude than at present. They do not urge that this altitude was maintained throughout the period, but that it existed long enough to make extensive snow fields, from which ice moved over adjacent regions.

Altitude alone cannot make an ice sheet. In many of our continents to-day there are extensive areas of great altitude, but no large snowfields. More essential than altitude, in inducing glaciation, is precipitation. A region may be but slightly above sea level; if its winters are long enough and a heavy snowfall occurs, which the succeeding summers do not waste, eventually ice will be formed. Therefore, the relation that an area bears to winds and the consequent precipitation, and the relative length of its summers and winters, are important elements in the probability of glaciation.

Change in position of the earth's poles. It was once thought that the earth's interior was in a hot, liquid, condition, and that man and other organisms lived on the cooled, solidified crust. On these premises, it was urged that tidal influence might shift the polar areas into lower latitudes, the "crust" slipping on the molten or plastic interior, thus changing the geographical location of the the glaciated regions, and inducing the development of ice fields in regions which were shifted to the polar positions. This liquid interior and thin crust theory is no longer accepted; physicists have taught us its impossibility. If the premises were correct, and if glaciation were always developed at the poles, the explanation would certainly account for temperate zone, and even tropical ice fields.

Change in eccentricity of the earth's orbit. This theory was advanced by James Croll.[3] That the eccentricity of the earth's orbit is not constant, is an accepted fact. The present difference in the earth's distance from the sun between the perihelion and aphelion positions is about three million miles. The direct heat received from the sun varies inversely with the square of the distance. When the eccentricity is at its maximum, the difference

[3] *Climate and Time in their Geological Relations* (1890), pp. 312–328.

between the perihelion and aphelion positions is about 14,000,000 miles; and the heat received at these two positions varies as 19 to 26. At the present time, the winter of the northern hemisphere occurs when the earth is nearer the sun; in 10,500 years the earth will be nearer the sun in our early summer. If winter in the northern hemisphere should come at the aphelion position, we would be about eight and a half million miles farther from the sun than now, and in consequence would receive one-fifth less heat in winter and one-fifth more in summer. If aphelion winter of the northern hemisphere should coincide with the maximum eccentricity of the earth's orbit, the winter would be 36 days longer than the summer.

The above are some of the important facts that led Mr. Croll to associate our glacial period with astronomical conditions. This explanation is ample to account for low temperatures, that would insure precipitation, if any fell, in the form of snow. If we knew approximately the time that has elapsed since the Pleistocene ice sheet commenced to develop, we could tell whether winter in the northern hemisphere happened at the time of the earth's maximum eccentricity of orbit. But there does not appear to be an agreement among students of astronomy, in reference to the variation of the earth's eccentricity during the past. We do not yet possess data of the behavior of other planets of our system, extending over enough time to make it certain that variation in their position might not vitiate our present conclusions of the past changes in the earth's eccentricity of orbit. The other planets probably account for the earth's orbit not being circular, and, as their alignment changes, the earth's orbit must also change. In any event, Croll's explanation makes a strong appeal to some students of the subject.

Variation in the content of the earth's atmosphere. Our present atmosphere is well understood. We know the gases it contains and the proportion in which they exist. A study of the earth's strata of the past geologic periods, and the life which existed when these rocks were being deposited, points to very appreciable variations in climate. During the Miocene period, animals of tropical waters lived in high latitudes. During the Pennsylvanian period, it is customary to hypothecate a mild and moist climate; this conclusion arises from a study of the flora that existed. It is quite universally agreed that climatic changes have taken place in the earth's past.

Practically the only source of the surface heat of the earth, worth considering, is the sun, and according to present ideas of earth origin, this has always been the great source of heat. Sunlight warms the surfaces exposed to it. How long the heat remains in these surfaces depends upon their capacity for radiating heat. Some rocks hold heat longer than others; water holds the heat longer than any rock. The sun's rays, coming through the atmosphere, do not appreciably warm the atmosphere, but heat radiated from the warm surfaces of the earth does raise the temperature of the atmosphere. If the heat thus radiated were kept near the earth, or if the atmosphere were kept quite constantly warm, climatic conditions would alter.

Some gases act as blankets and keep radiated heat from passing quickly through them. Water vapor and carbon-dioxide belong to this class. It is supposed, therefore, that if the present content of carbon-dioxide and water vapor in the atmosphere were increased, the mean annual temperature of the earth woud be raised accordingly. One estimate says that two or three times the present content of carbon dioxide would raise the average temperature 8 or 9 degrees; and that if the present content of carbon-dioxide were reduced one-half to two-thirds it would lower the average temperature 4 or 5 degrees. The former condition of higher temperature is thought to represent the climate of the Miocene period; the latter condition, that of the Pleistocene. Studies of the rocks have led students to conclude that there has been a variation in the amount of carbon-dioxide in the earth's envelope during the past, and it is further concluded that the same causes will bring about in the earth's future a repetition of this variation. To discuss this latter point completely, would involve much detail that would hardly be in place in these chapters. Those interested are referred to the literature where the matter is fully considered.[4]

This theory of change in the earth's atmosphere makes a stronger appeal to the students of the present day than do any of the other theories advanced to account for the glacial period.

[4] Chamberlin and Salisbury, *Geology*, vol. iii, (1906), pp. 432–445.

COMPLEXITY OF THE PLEISTOCENE GLACIAL PERIOD

In this discussion, so far, I have spoken of the glacial period as a unit, as a simple affair. For a long time it was so considered; but more careful study of glacial deposits has shown that all drift is not of the same age. The age of glacial deposits is determined somewhat by the extent of weathering which they show. In a given time, chemical agents will make certain changes in drift of certain content. Multiples of that time unit would bring about more marked changes in the same drift. Rainfall and resulting stream courses gradually roughen all surfaces. If we compare two drift plains, one of which is thoroughly creased by stream courses and the other but slightly altered, the rainfall of the two areas being the same, we conclude that the former has been subject longer to sub-aërial weathering. These two distinctions are the most obvious of the many that have led students to differentiate glacial deposits on the basis of age.[5]

Pleistocene stages. The drift in parts of northern North America represents at least four and possibly five distinct ice advances. It is thought that between each advance the glacier may not have disappeared completely; it probably receded towards the dispersion centers, and then readvanced. But the time interval between a recessional and the next forward movement was sufficient for some progress in the weathering of the drift last deposited, for the development of stream courses over some of the drift area, and for the reëstablishment of flora and fauna. As a given ice sheet receded, it is probable that plant life followed its margin closely. The types of plants that kept nearest the ice were necessarily arctic and subarctic; other types came into the same zone as the ice retreated further. When the glacier advanced again over that territory, part of this vegetation was buried and later drift was deposited on top of it, while much suffered degradation along with other materials. Decayed plant remains, mingling with disintegrated rock, develops humus or the soil. To-day in some localities we find two till sheets separated by a soil zone, frequently containing logs and other vegetation. Remains of animals are also sometimes found in connection with the succeeding drift

[5] Leverett, *American Journal of Science,* vol. xxvii, (1909), "Weathering and Erosion as Time Agents," pp. 349–368.

sheet; thus we infer that animals had reoccupied the area after the former ice had gone.

Each extension of ice did not attain the identical marginal limits of the preceding sheet. For example, the glacier of the last epoch, the Wisconsin, throughout part of the glaciated area, extended beyond the limits of any preceding ice sheet. This, however, was not the universal condition. The imbricated relationship exists at sufficiently scattered points to indicate very satisfactorily the conclusions about the succession of the drift sheets.

While we more commonly assert that the early sheets of drift are more weathered than are the later, at the same time, it must be borne in mind that the better understood evidences of weathering may be more obvious in the deposits of later ice sheets. Oxidation, particularly of deposits with a ferruginous content, gives rise to the rusty and yellow appearances usually asociated with weathering. The lower parts of an earlier drift sheet, which had not been reached by weathering agents before the area was spread over by a later ice sheet and permanently buried, may show much less indications of weathering than does the surface part of the most recent drift sheet. Furthermore, the early over-ridden deposits would be made compact, and percolating ground water might more closely cement its parts, thus indurating it. Again, this early drift, when over-ridden by later ice, would suffer strains and stresses, and joints and faults would be induced thereby.

Where a post-glacial river has cut a channel through succeeding drift sheets, or where the wave work of lakes has developed a cliff exposing different drift sheets, we have the best opportunity of studying their appearance. When a later sheet failed to reach the margin of an earlier sheet, we can best observe the different extent of stream development on their surfaces.

OTHER GLACIAL PERIODS

It is not many years since geologists gave general credence to the scattered reports of workers in South Africa, India and Australia, concerning the existence of glacial conglomerates belonging to the Permian and Cambrian periods. Many had supposed that the Pleistocene glacial epoch was itself convincing proof of the earlier theory of molten interior and the cooling crust

of the earth. The extensive continental glaciers of the Quaternary fitted well into the early idea of earth-origin.

To day it is generally accepted that our rock horizons show four distinct glacial periods. The earliest, and the only one which is not as yet fortified by data convincing to all students, is connected with the Proterozoic period. The next belongs to the Cambrian, then the Permian, and finally the Pleistocene, the most recent period.

Evidences of earlier glacial periods. Metamorphosed glacial products become clastic rocks. Glacial gravels and sands, when indurated, can not always be distinguished from similar sediments of non-glacial origin; but glacial conglomerates usually have distinctive features. The heterogeneity of this conglomerate usually distinguishes it from any other clastic rock that is catalogued as a conglomerate. Whereas it is possible to find in rivers conglomerate stones that have been striated while they were held fast in floating blocks of ice and came in contact with other rock, yet such striated bowlders are very rare. Consequently, a conglomerate rock which contains many polished and scratched bowlders is of glacial origin. Furthermore, the matrix of glacial conglomerate, containing, as it does, a large percentage of bowlder clay, has distinctive features, which are obvious when examined in thin sections under a microscope. While a widespread conglomerate, with numerous striated bowlders in a matrix of glacial clay, is good proof of a glacial period, at the same time, to remove the matter entirely from doubt, such a conglomerate, locally at least, should overlie scored, grooved, or striated rock surfaces; glaciation is the only agency that is known to thus alter rock surface. These two lines of evidence make the definition of a remote glacial period conclusive.

Proterozoic glaciation. Of these earlier glacial invasions, the evidences supporting this one has only recently been published. In Canada, in the vicinity of Sudbury, Professor Coleman of Toronto, over two years ago, studied a conglomerate rock, which he interprets as glacial in origin. His later reports array proof which has been accepted by many other geologists. Field work has not yet shown how extensive this conglomerate is. It should be remembered that, according to current ideas, our continent was very small during the Proterozoic period; also, that the rocks then in existence have suffered much from weathering and erosion

during later periods. It is possible, therefore, that an extensive glacial formation of this early period may have been quite largely removed during later time.

A more interesting fact, however, connected with the Huronian ice age, is the bearing it has on formerly accepted ideas of conditions that prevailed immediately preceding the Proterozoic period. The rocks of this early period are sometimes thought of as cooled magmas or congealed liquid material of the parent earth; and the absence of fossils in these early rocks has been explained by saying that the surface of the earth was then so hot that life could not exist thereon. If glacial conditions existed in a particular part of the Proterozoic continent, it is quite conclusive evidence that there, at least, the surface was not warm.

Geologists of Norway also report conglomerate, suggesting glacial origin, belonging to rock horizons that appear to correlate with the Huronian of North America. If their correlation is correct, this early period witnessed glaciation in two distant parts of our sphere.

This early glacial period has a significant bearing on our ideas of the origin of the earth. Such refrigeration could hardly be possible under the nebular hypothesis. It is, however, entirely possible under the planetesimal theory of earth-origin.

The Cambrian glaciation. In connection with studies carried on in China, under a Carnegie grant, by Bailey Willis and others, a conglomerate horizon of glacial origin was located in the upper Yangtze valley. This horizon contains beautifully striated bowlders, as well as other conclusive evidences of glacial origin. Its location in the geologic scale is also made definite by the fact that it immediately overlies a formation whose fauna is well known. Glacial conglomerate of the same age has been identified in south Australia.

The Permian glaciation. In India, Africa, and Australia the existence of glacial conglomerates belonging to this period has been established. No other pre-Pleistocene glaciation is more thoroughly understood. In south Africa, these conglomerates were pointed out a long time ago, but students were very slow in accepting the interpretation. The time correlation of beds in such distant parts is made definite by relationship to other horizons bearing well known fossils. In south Africa, the glaciated surfaces underlying these conglomerates are as beautifully preserved as

surfaces similarly altered during the recent ice age. Weathering and erosion have locally removed the conglomerate, revealing the scored and grooved rock surfaces beneath.

Detailed studies in Australia show that the Permian glacial period there was complex, in that the ice did not make an advance and then disappear, but there were several readvances, spaced by warmer conditions, producing in succession till and shale, separated by other deposits. Coal beds are found in some of these interglacial periods. Furthermore, the flora of the horizons itself reflects glacial climatic conditions.

Much speculation is possible on the basis of these three widely separated regions containing glacial conglomerates of the same age. Did all three belong to an extensive land area occupying the position of the Indian ocean? Whatever may have been the association or disconnection of these three distant tracts, it is certain that climatic conditions very unlike the present then existed. The Indian glaciated area lies near and north of the equator; the Australian region, not very far south; while the African is a little farther away. Possibly in the Permian ice sheets there is a suggestion as to the cause of glacial periods. Unless we can prove marked shifting in the location of the poles, it must be accepted that glacial conditions can exist in the tropical belt.

In South America, glacial conglomerate belonging to the Permian period has been studied. The matter has recently been under investigation, but the reports of the work are not yet available.

Conclusions. With four well established times of glaciation scattered through the geologic scale, it would appear that glaciation is a normal, not an abnormal feature in earth-history. When men labored under the idea that there had been only the one glaciation, it was interpreted as an abnormal condition. Whether these four periods are rhythmically spaced, we do not know. Man has not yet learned how to measure geologic periods. We merely feel that the Permian is very much nearer the present than is the Cambrian; but this gives us no definite conception.

Professor Chamberlin, who has most convincingly explained the carbon-dioxide and water-vapor cause of glaciation, has shown how the past glaciations may be a normal feature of earth-history. Briefly the explanation is this: With continued base-leveling of land areas, the epicontinental parts of the seas were broadened

and on the lowered lands plant growth became more luxuriant. As the base-leveling proceeded, the limestones and other rock horizons were disintegrated; the amount of carbon dioxide in the ocean, as well as in the atmosphere, was increased. Extensive lime deposits were again made and luxuriant plant life spread over the base-leveled continents. With the formation of limestone, the quantity of carbonates was much reduced in the oceans; and the unusual consumption of carbon dioxide by vegetation tended to deplete the atmospheric content of this gas. With a reduction also of the water-vapor of the atmosphere, heat was quickly radiated from the lands. The mean annual temperature of the earth was much reduced; in these parts where ocean currents, winds, and land areas maintained the correct relationship, precipitation in the form of snow followed. Succeeding the base-leveling, deep-seated crustal movements, consequent probably on the over-loading of the ocean basins and lightening of the continents, tended to uplift the land and possibly also to elevate some submerged tracts, either forming new lands, or at least changing the course of ocean currents. This matter of elevation of land areas is a contributory factor, probably, in deciding the form of precipitation; furthermore, the increased elevation of the lands facilitated the carbonation of rocks, thus tending to further deplete the atmosphere's carbon dioxide. Only in the parts of continents where the prevailing winds and sufficient altitude, or the correct latitude, combined to induce snow, did ice caps develop. Snow-fields might result, therefore, either in the tropical or in higher latitudes.

It is well understood that the direction of ocean currents is partly controlled by the location of land areas. If, for example, North and South America were not connected, and the northern part of the equatorial drift current were to continue directly west, instead of being diverted northward in the "Gulf Stream," as it now is, great changes in the climate of Europe would result; there might be greater snowfall in western Europe. On the basis, then, of a cyclic variation in the atmosphere's content of carbon dioxide, following base-leveling periods, and their possible coincidence with such changes in the outlines of continents as might alter the courses of some ocean currents, we have, at least, a working hypothesis for the several glaciations and their geographical distribution during geologic time.

THE GLACIAL DEPOSITS OF OHIO

Local topography is always a factor both in the distribution and in the nature of glacial deposits. The gross relief features of a region determine the outline of the ice during its precessional and recessional movements. Minor relief features and the quantity of waste material present have a bearing on the amount of drift which the moving ice may locally acquire. Since moraines and other glacial deposits represent the débris within the ice, it follows that conditions tending to give the ice a load are factors to be considered in studying the drift of an area.

Glacial lobes in Ohio. Before the glacier had moved into Ohio, the lowland, which is now the basin of the present Lake Erie, induced in its front a pronounced lobation. This basin gave the ice sheet its general outline through Ohio and part of Indiana. Topographic features in Ohio determined the grosser marginal details on the south side of that lobe.

Commencing in the northeast part of the state, we will consider the relief features that determined the shape of the glacier margin. Preglacially, the Grand River valley was mature. For this reason, its course was filled by an extension of ice reaching ahead of the main sheet. Along the margin of the Grand River lobe, moraines accumulated. It is by a study of the moraines that we are able to-day to outline the form of these lobes. During the extreme reach of the glacier, the Grand River depression ceased to impress its topography on the shape of the ice front, as the sheet had extended south beyond the headwaters of the valley. Again, during the recessional stages, the lobe pattern of this valley became evident.

When the ice sheet was near its southern limits, south of or in the vicinity of Canton, its front described an arc, the western limit of which stood near Mansfield. This minor lobate form appears to be due rather to higher bounding altitudes than to a marked valley. If a valley lowland existed here, its axis should be along a line from Millersburg to Wooster. The drift here is heavy; and some work has already been done, showing that former drainage lines have been buried.

The Scioto River valley induced a beautiful lobation in the ice front, till it had retreated north of Marion. Between Marion and Chillicothe are many rudely concentric lobate moraines,

indicating the successive positions of the glacier in its recessional movement through the Scioto valley.

The Miami River valley also occasioned a lobate outline in the ice sheet, most pronounced at its maximum extension. This relief feature appears to have imposed itself upon the ice only while its margin was south of Troy. The western part of the Miami lobe included territory in Indiana. The highland in Logan county accounts for the irregular course of the Erie lobe moraines in that vicinity, as if they were festooned at a point north of Bellefontaine.

After the ice sheet, during its recessional stages, had withdrawn northward from the above valleys, its outline was determined by the basin of Lake Erie. Therefore, in the northern part of the state the moraines are concentric, bordering this basin; whereas, south of this area they are arranged in a series of loops, occupying the valleys just described. Between these minor basins, the ice formed a reëntrant angle. The position of this reëntrant angle is marked by the coalescence of the drift of the lobate moraines; consequently, we have concentrated drift along a more nearly north-south line wherever the lobes blended. Between the Miami and Scioto lobes, this blending of frontal moraines accounts for the thickened drift northward from Springfield to the vicinity of Kenton. On the eastern side of the Scioto valley, the drift is heavy from Lancaster to Mansfield; this thickened drift marks the margin of the Scioto ice lobe, east of which there was no corresponding lobe until we reach the meridian of Millersburg. The depression, whose axis appears to be determined by the line connecting Millersburg and Wooster, blends into that of the Grand River lobe along the meridian of Canton, between which place and Akron the drift is very thick.

Ice lobe margins. Leverett's map of the drift in Ohio gives the distal positions of the glacier, as indicated by the more conspicuous retreatal moraines.[6] To determine accurately the minor details of the ice front will require more study. Neither our Federal nor State Surveys have been able to take up this work. It will necessarily require a great deal of time and expense. In some parts of our state, particularly in Licking County, on the east side of the Scioto lobe, closer study has been given the out-

[6] *Monograph XLI,* U. S. Geol. Surv. (1902), plate ii.

line of the ice at its extreme position. It has been found that the glacier margin varied in shape with the topography. Wherever valleys existed, minor tongues extended beyond the main body of the ice; the relief in eastern Licking County is irregular, consequently there were several ice dependencies. Consulting a map[7] of the ice front in this county, one may note that in the vicinity of Wilkins' Run a minor dependency extended eastward over a mile; that along the parallel of Newark, a dependency reached into Muskingum County, a distance of some six or seven miles beyond the main glacier. Eastward from Buckeye Lake, another dependency extended through Jonathan Creek; this latter ice tongue appears itself to have been irregular, sending out secondary branches into confluent valleys.

Many interesting problems are connected with the more accurate mapping of the ice front. It is hoped that students in several parts of the state may take up this work, and that eventually the glacial boundary line in Ohio may more accurately represent real conditions.

ICE FRONT LAKES

The divide between the Ohio River and Lake Erie basin drainage is to-day very irregular. The rivers which flow into Lake Erie send their waters to the Atlantic by way of the St. Lawrence. If a barrier should be raised across the St. Lawrence at the eastern end of Lake Ontario, this lake would enlarge; if the barrier were sufficiently high, and a similar obstruction were placed across the Mohawk valley near Rome, N. Y., Lake Ontario would blend eventually with Lake Erie. If such a barrier stood only across Niagara River, the waters of Lake Erie would continue to deepen till some other outlet were discovered.

During its recessional stage, as soon as the ice sheet had withdrawn northward from the divides between the tributaries of the Ohio River and Lake Erie, water began to pond along its margin. This happened at many disconnected places. Each local lake thus formed increased in size till its waters flowed southward towards the Ohio, and, with further recession of the ice sheet, these small local lakes grew larger, and blended. At first they were distinct, because local divides existed between them, divides that

[7] F. Carney, *Journal of Geology*, vol. xv, (1907), pp. 488–495, fig. 2.

had a direction transverse to the front of the ice. The ice withdrawing down the slope of these divides, all of which inclined to the north, allowed the local bodies of water to coalesce. In time a lake paralleled the front of the ice, and had an outlet westward through Fort Wayne, Indiana. The name, "Maumee," has been given this ice front lake.

Lake Maumee. Under the direction of the Ohio Geological Survey, during the years 1869 to 71, G. K. Gilbert, in connection with other investigations in northwestern Ohio, did the first work in mapping this lake, noting its beaches and other shore phenomena. He mapped the morianic ridges also, thus determining the outline of the Erie ice lobe, in front of which Lake Maumee stood.

The wasting of the glacier itself, with the accession of the drainage from the basin south, was so great that water ponded rapidly in front of the ice sheet. The general trend of the shore of this lake in Ohio was east-west; in Michigan, north-south; in form it was saddle-shaped, resting against the Erie ice-lobe. After the Fort Wayne outlet, now 735 feet above tide, was uncovered, Lake Maumee continued its overflow in that direction till the ice had retreated far enough to disclose, somewhere north or east, a place of lower altitude; then a new overflow channel would be established. This, however, did not occur till the ice sheet had withdrawn northward in Michigan to the vicinity of Imlay, in Lapeer County. This new overflow channel was revealed near the reëntrant angle between the Erie and Saginaw bay lobes; its altitude is only fifteen to twenty feet lower than the Fort Wayne channel.

I have already explained (p. 195) how minor advances sometimes characterize a general recessional movement of the ice. In consequence of such oscillations, it is thought that the Fort Wayne outlet was temporarily used for short periods even after the Imlay channel had been uncovered. The overflow channels of ice-front lakes, particularly when near the ice itself, as was the case in the reëntrant between the Erie and Saginaw lobes, carried great quantities of water, sometimes laden with cutting tools. For this reason the channels themselves were degraded, and, as they were cut down, the general level of the lake declined. At first, it is probable that the altitude of the Imlay and Fort Wayne channels did not differ much. If the Imlay outlet were in use a considerable period of time, this lower stage of Lake Maumee should be

marked by beaches and other shore phenomena corresponding to, but lower than, the original beach.

With a further retreat of the ice a new outlet north of Imlay was revealed, the Ubly channel; its altitude is about thirty feet lower than the former. In consequence, the level of Lake Maumee fell this amount.

The Whittlesey stage. This lower lake is called Whittlesey, after one of the early geologists of Ohio, Colonel Whittlesey, who was connected with our first Survey, organized in 1836. During the Whittlesey stage, a continuous sheet of water extended across northern Ohio. This lake was at least 160 feet deeper than the present Lake Erie. It drained across Michigan into glacial Lake Chicago, the name used for the water in front of the Chicago ice lobe. Lake Chicago overflowed through the course followed now by the Chicago sewage canal, into the Illinois River, thence to the Gulf. The Erie basin ice lobe, during the Whittlesey stage, blended eastward into the margin of the glacier extending across western New York. Therefore, Lake Whittlesey reached from the state of Michigan, on the west, to Central New York, on the east. Its margin across Ohio is marked by a splendidly developed shoreline, which I discuss in a later section.

It is evident that Lake Whittlesey endured till the ice had withdrawn from some divide in New York state lower than its overflow in Michigan. The ultimate control of the western outlet, then, was an altitude that might be revealed along the southern slope of the Mohawk lowland. During the entire existence of this lake stage, the ice sheet filled the Mohawk area, and abutted the Catskill region south. It is very likely that before the close of the Whittlesey stage, its waters flowed both to the east and west. This condition would naturally follow when the ice sheet should withdraw sufficiently down the southern wall of the Mohawk valley to disclose a level not very much higher than the Ubly outlet. With a slight difference in the level of two channels, a continuous west wind might cause an eastern overflow, temporarily at least. Thus, for some time, Lake Whittlesey may have overflowed into the Atlantic by the two routes. When, however, the ice had appreciably retreated in the Mohawk lowland, the level of Lake Whittlesey was bound to fall correspondingly, and a new outlet be permanently established.

Lake Warren. This next lake level, which overflowed through the Mohawk valley, is thus named. Its outline may be traced entirely across Ohio. Lake Warren included the ponded waters in the Saginaw Bay valley, waters in the Detroit region, waters extending across the present basin of Lake Erie and continuously through Cental New York. Warren thus had many times the area of our Lake Erie. How long it existed we have no way of telling. Judging from the pronounced beaches and other shore phenomena which now mark its level in Ohio, it must have endured a long period. Its existence was terminated when the ice retreated sufficiently to disclose a still lower outlet.

THE ORIGIN OF LAKE ERIE

Much has been written on the origin of our Great Lakes. In genesis they are associated; therefore, it is difficult to discuss one without going into the origin of all of them.

Lakes in general. It is well to remember that lakes are always short-lived. Frequently they are but broad portions of rivers; as the river lowers its bed, these broader sections are drained to normal channels. Other lakes occupy basins due to various causes, but in time, the outlets of these basins will be cut down and the lakes be drained; the only insurance against such a termination of a lake is found in basins below sea level, in a humid climate; in this case, with sufficient rainfall, the lake surface will rise till it reaches an outlet; the erosion of this outlet, and the deposits of streams in the basin will eventally bring the lake to an end. Along ocean borders bodies of water are sometimes isolated, forming in a short time brackish lakes and eventually bodies of freshwater; such lakes are also temporary, because vegetation, generally with the aid of sediment from streams, fills them. Of the several details that make up the features of our land surfaces, few, if any, are less enduring than lakes.

It is an obvious fact that those parts of the continents which have many inland bodies of water have been recently glaciated. South of the ice margin in North America and in Europe, very few lakes exist. Our knowledge of the conditions that surround the lakes of Africa is not sufficiently complete to assert their origin; it has been suggested that part of them, at least, occupy rift valleys, that is, depressions due to the subsidence of a long block of the crust

between adjacent portions that remained stationary; the valley of the Jordan and Dead Sea is of this origin. Since, therefore, most of our lakes occur within the glaciated portions of the continent, and since Pleistocene glaciation is so recent, it is easy to accept the conclusion that lakes are geologically temporary.

The St. Lawrence drainage basin in preglacial times. Our Great Lakes are virtually but parts of the St. Lawrence River. The St. Lawrence River then is very peculiar. Normally, a river and its tributaries form a symmetrical outline, and among these tributaries there is an orderly arrangement. It is commonly thought that the Great Lakes occupy preglacial stream courses. The St. Lawrence and the lakes within its basin do not conform to a normal drainage pattern. Lakes Superior and Michigan unite in a manner that is not out of harmony with the confluence of stream tributaries; but, when considered in connection with Georgian Bay and Lake Huron, they together present an unusual alignment for drainage courses. It is very evident that the St. Lawrence drainage is abnormal.

Whatever may have been the pre-glacial topography of this area, the present Great Lakes are not parts of a former continuous river system. Before the ice sheet spread over the region, valleys must have existed. The perplexing question is as to the direction of flow of these valleys. Many conjectures have been offered on this point. Most of these suggestions are based upon the established presence of buried channels, contiguous to many of these lake basins. It is thought that if a buried channel, entering Lake Erie, shows rock removed to a depth of 470 feet below the lake level,[8] some stream to which the channel was tributary, must have occupied its basin preglacially; and if this tributary has such a deep channel, the major must have been still deeper. About the margins of some of the other lake basins are found buried channels, the rock beds of which are even below sea level. Along the continental shelf, soundings have revealed canyon-like depressions, continuous with rivers now entering the Atlantic; thus we speak of the drowned canyons of the Hudson and St. Lawrence rivers. The submerged courses of these streams over the continental platform, and the existence of deep buried valleys about the Great Lakes of to-day, have led to the suggestion that pregla-

[8] Warren Upham, *Bulletin Geological Society of America*, vol. viii, (1897), p. 8.

cially, this part of North America must have had a much higher altitude. Such an hypothesis would make it much easier to understand this relationship of deep channel-cutting. At the same time, to accept a genetic association between canyons across the continental shelf and those farther inland would require our altering the accepted idea of river and valley development. While, in its headwater area, a river may occupy deep gorges, contemporaneously, its down stream section is found in wider valleys, and eventually, before reaching the ocean, the river's course should regularly be very old and flat. If, then, the submerged canyons and buried channels represent stream-cutting due to an uplift, they cannot be contemporaneous in origin. Many students are of the opinion that along all our continents the buried channels need not imply former greater altitude of the land areas, but instead a tendency of the continents to creep seaward, thus carrying with them the drainage patterns existing.

Just what is the origin of the buried channels about the present Great Lakes is an unsettled question. Before any conclusion can be reached, it will be necessary to know more thoroughly the extent to which buried valleys and channels exist; and since such knowledge is established only through drillings, it will probably be a long time before this desired information is obtained.

On one point, there appears to be complete agreement among geologists: The present lake basins, preglacially, were depressions or valleys occupied by streams. When, however, these students reconstruct that preglacial drainage, many opinions at once arise. I will state, briefly, the more widely published reconstructed drainage plans of this area. Among the early suggestions it was stated that preglacially, part at least, of the area of the present Great Lakes was drained eastward through the Mohawk lowland. This assumption appears to have been suggested by the buried valleys south of Lake Ontario. To lead waters from the buried gorges of the region south of Lake Ontario, that could have been associated genetically with the continental-shelf canyons, would require a deep valley through part of the Mohawk lowland. No such valley has been found; furthermore it appears to be well established that it never existed. In the vicinity of Rome, N. Y., across the meridian of which, this hypothecated valley or channel must have led, continuous rock exists. Bearing on this point, however, and somewhat in harmony with the origi-

nal suggestion, are the recently discussed buried channels of the Hudson valley, channels brought to light in engineering projects connected with the water supply of New York City.[9]

It has also been thought that the preglacial drainage of the Great Lakes area reached the ocean as it does to-day. The configuration of the present St. Lawrence valley precludes any such hypothesis. Its originator so grants, but he explains that since the close of the Wisconsin glacial epoch, tilting of the land has locally lifted the floor of the St. Lawrence valley, and that now its altitude is much greater than formerly. That land tilting of this nature has taken place in postglacial times is already well established through a study of the deformed beaches of ice front lakes. If the reconstructed drainage of the Great Lakes basin reached the Atlantic through the St. Lawrence area, the amount of land deformation required would certainly be beyond any conception held by geologists. This plan ot reconstructed drainage has very few advocates.

Others have shown how the Great Lakes, with the possible exception of Lake Ontario, occupied depressions which preglacially drained towards the Mississippi basin. This reconstructed drainage is most generally accepted. Some differences of opinion appear in details. One investigator hypothecates a former river that followed, in general, the basins of the present Michigan and Superior lakes; another stream having its axis through Saginaw bay, and with its tributaries draining most of what is now the Huron basin and Georgian Bay; while the Lake Erie basin was drained by another river, whose headwaters included part of the Lake Ontario region. These three rivers had courses to the southwest. No attempt has been made to work out any further details as to their southern courses. This same geologist hypothecates another southflowing stream from the eastern end of Lake Ontario's basin, reaching the Atlantic through the Susquehanna system.

Local warping. Deformative movements of the earth's crust have been known to so bow original horizontal rocks as to produce a basin in which drainage, accumulating from the adjacent slopes, would form a lake. Where such a movement has made a basin, a study of the rock attitude should reveal the fact. Apply-

[9] J. F. Kemp, *American Journal of Science*, vol. xxvi, (1908), pp. 301–323.

ing this theory to the Great Lakes, it is found that Superior occupies such a synclinal basin; but it is generally understood that the other Great Lakes do not occupy warped basins.

Glacial erosion. There are very few geologists to-day who do not believe in the potency of glaciers in eroding rock basins. Basins thus produced, however, are almost always over-deepened portions of preglacial valleys. Concentrated ice erosion, in a portion of such a valley, is the explanation offered for the stupendous deepening noted in a few localities. Examples of basins thus produced are Lago Maggiore and other lakes about the Alps area; many of the Lochs of Scotland; Lake Chelan and a few others in the Rocky Mountain region; and part of the Finger Lakes of New York state. It is noted that all of these are long narrow lakes quite unlike the Great Lakes. Nevertheless some geologists have advocated the same theory for the origin of part, at least, of the Great Lakes. Some years before ice erosion was invoked to account for deepened valleys, J. S. Newberry, then connected with the Ohio Geological Survey,[10] urged that the rock of the Erie basin was easily carved by ice and had been sufficiently basined to account for the lake. His suggestion was given very little credence at the time.

When we consider the shape of some of these lake basins, particularly Lake Erie, it does not require very much basining of the shales to produce them. The average depth of Lake Erie is only 70 feet and its greatest depth 204 feet. Cross sections of this basin show how shallow it is, relative to its area. It does not seem at all improbable that the Erie-ice-lobe sufficiently eroded the fissile shales beneath it to make this shallow basin.

The erosive work of the continental glacier was accomplished almost entirely by the lobes and dependencies along its margin. Back from the front, where the ice was deep, it is not likely that the subjacent rock was very effectively abraded; but at the front, where a lobe or tongue, shod with tools, continued for centuries to wear and grind the rock beneath, some effect was certainly produced. Furthermore, these marginal forms of the ice sheet received the concentrated motion of the great ice mass in the rear; if the ice is a small lobe or tongue fitting into a valley, the side walls and boundary divides of which tend to obstruct the move-

[10] Vol. i, (1873), p. 49.

ment of the glacier, the great field of ice in the rear uses the valley tongue as an outlet, and consequently lines of movement converge towards the axis of this tongue. Such a tongue, or dependency, becomes a strong erosive agent, provided it is carrying the proper tools. In a similar manner, but in a slighter degree, a lobe of ice receives the onward impulse of a greater area in its rear; but the lobe is larger and is not occupying so confined a basin, consequently the erosive work done is not comparable to that accomplished in narrower valleys. Through the work of an ice lobe, a shallow basin like that of Lake Erie may easily be produced; under the concentrated work of a valley tongue, the deep Lochs of Scotland and the grossly overdeepened Ticino valley of Italy are natural.

While ice erosion was a factor in developing the basin of Lake Erie, at the same time it is apparent that land tilting has had something to do with the present size of this lake. In its western end the lake is shallow; if the eastern end, at the mouth of the Niagara River, were depressed 10 feet, the lake counties of the state, west of Huron River, would have their areas increased. Land tilting in postglacial times has tended to drown the western end of this basin. There was one period, since the ice retreated, when the lake was only a small fraction of its present size; indeed, according to some investigators, the basin held no lake, only a river. The obvious effect of the postglacial tilting, in increasing the area of a lake in the Erie basin, in nowise detracts from the part taken by ice erosion in making the basin. To be assured that glacial erosion operated here we have only to recall the evidences of it on the islands about Sandusky; the limestone resisted the corrasion of ice more than did the neighboring shales.

To what extent glacial erosion has been a factor in the development of the basins of the other Great Lakes cannot be proved. The amount of erosion, if the glacier made their present depths, is varied. Lake Superior is the deepest, but ice erosion is invoked less in accounting for its basin than in the case of the other lakes. Lake Michigan occupies a rock basin; its maximum depth, 870 feet, at first thought, would indicate a great deal of erosion. When, however, we consider its length and the width of the basin, as it is brought out in a cross section, with the same horizontal and vertical scales, this depth does not appear so great. Lake Huron, having a maximum depth of 702 feet is also in a rock basin.

We have absolute proof that ice lobes occupied each of these basin areas for a long time. The concentric moraines about the basins give us the pattern of each lobe at several recessional stages. Knowing that heavy bands of drift in recessional moraines usually contain a high percentage of local material, we infer that these concentric moraines are witnesses of long continued ice-erosion of the basins. A similar arrangement of moraines south of Lake Erie shows that its basin was also subject to the same mechanical work.

The orientation of the Huron basin does not expose it so directly to the erosion of ice from the Labrador dispersion center, as is the case with either Michigan or Erie. The direction of striae, and the arrangement of moraines, afford the evidences on which it is concluded that this part of the Great Lakes' area was under the influence of the Labrador center during at least the Wisconsin epoch of the glacial period. Whether the Labrador center exercised the same control during all the preceding glacial epochs is not known. The direction of Huron's basin indicates possible erosion from the Keewatin center. There is no reason to infer that, during the earlier epochs of the Pleistocene, these two dispersion centers controlled the same regions southward that they did during the last epoch; but at present we have no evidence that suggests a different ice control for the earlier epochs. Possibly, in time, we may have sufficient knowledge of the kinds of rocks found in the drift, and their particular sources in the north, to demonstrate whether there was always identity in the ice movements of the several epochs from the two dispersion centers.

In the absence of a more convincing explanation, it is probable that students will continue to regard these lake basins as largely the product of glacial erosion. We cannot infer the amount of over-deepening by ice, as we have no measure of the depth of these valleys before the ice entered. The most reasonable way of approximating the amount of ice erosion in any particular one, say the Michigan basin, is to note its depression below a line which probably represents the gradient of the former valley. The lake basin is rock-bound at either end. Allowing something for the erosion at these termini, in case it is thought that one end has suffered more erosion than the other, the line connecting their levels will be parallel to the gradient of the preglacial stream. A line drawn along the lowest bed rock of the present basin, there-

fore, represents the limit of erosion in the plain determined by the two lines.

Several of the other factors briefly discussed doubtless had some part in producing the Great Lakes. The most inclusive theory of origin is that stated by Chamberlin: "The basins of the Great Lakes are regarded as due to the joint agencies of preglacial erosion, glacial corrasion, glacial accumulations, blocking up outlets, depression due to ice occupancy and general crust movements, together with possible unascertained agencies."[11]

OLD SHORE LINES IN OHIO

Three ancestral lakes of Erie formerly stretched across our state. Each of these left such evidences of its existence as the present lake is now engaged in producing. If you visit Lake Erie at any point, you will observe that the water is either cutting into the shore, which is either till or solid rock, or else it is piling up material which the waves have carried. In the former case the waves are undercutting a cliff; in the latter, constructing a beach. These earlier lakes must have done similar work; what they accomplished, either in cliff-cutting or in beach construction, depended upon their duration. Wherever the former lakes made cliffs in rock, the result was more enduring than if the cliffs had been cut in unconsolidated material. Wherever they built beaches of cobble and gravels, this material has held its shape longer than beaches constructed of clay and sand. The sharpness of development in the shore lines of former lakes is conditioned by the lapse of time since they were made. We would expect, therefore, in case these three shore lines represent lakes which lasted through equal time units, that the oldest one would now be the least distinct; it has suffered longest from weathering. On the supposition that there has not been an appreciable change of climate in this area during postglacial time, this method of determining the relative ages of old shore lines is fairly accurate.

Origin of shore lines. A lake occupying a basin either of rock or unconsolidated material, or a basin consisting of both, will alter its basin somewhat through solution. A body of water

[11] *Proceedings American Association Advancement of Science,* vol. xxxii, (1883), p. 212.

remaining absolutely static induces chemical alteration; limestone is thus corroded below the level of wave action. But the efficient weathering work of lakes is accomplished by waves which depend upon winds. Winds through friction of the atmosphere against the water's surface, roughen the surface into waves. The impact of the waves upon the shore, driving tools against it, cuts the shore. The effectiveness of wave work shows more readily on a steep shore. When the marginal part of the lake-basin has a gentle slope, wave work is slow in establishing a cliff; if the slope is very long, the waves may never form a cliff, but instead, will pile up material off shore, there constructing a beach. After such a beach becomes well developed, wave work may steepen its outer slope, or even cut it as a cliff.

At all places along the border of a lake the waves are either undercutting, or piling material up. At different times during the year, depending upon the strength of winds, both processes may be in operation at the same place.

The shape of a lake has much to do with the efficiency of wave work on its shores. The longer axis of Erie coincides approximately with the prevailing wind direction. As a result its shores have been subject to vigorous wave work, both constructive and destructive. In case the prevailing wind direction has been the same through postglacial times, and there is no reason to think otherwise, the ancestral lakes of Erie experienced similar effects. The vigorousness of wave work to-day may be observed at most any point along the lake. The lake cities have to make annual appropriations either for retaining walls to save their front, for lengthening piers, or for dredging to make it convenient for vessels to land.

The development of cliffs. Active wave work develops cliffs either in unconsolidated material or in rock. The slope of the cliff is determined by its material, being steepest in rock; but the process of cliff development is the same in either case. Waves impelled by the winds wear the cliff by impact alone; when the water carries stones, the cliff is cut more rapidly. At the point of attack, the cliff is undercut; when undercutting has proceeded far enough, the overhanging material drops off. As a usual thing, where cliff-cutting is in progress, the waves are strong enough to develop a current along the shore, which removes the blocks that have dropped into the water, as they are ground to bits by

the waves, thus keeping the base exposed to fresh attack. At some places on the lake, cliff-cutting has proceeded very rapidly even during the short period that the shores have been inhabited. Farmers have lost fields, and cottagers have had their property destroyed.

Beaches. Vigorous waves striking the shore are thrown some distance above the level of the lake. These waves push ahead of them the cobble, gravel, sand, etc., along the shore. Under the impulse of heavy winds, the huge waves drive material far up on the shore. This material then is pushed beyond the reach of waves. In the course of time a ridge is thus constructed, called a beach ridge. It consists of fine and coarser products, depending sometimes on the location of nearby cliffs, which furnish the material, and sometimes on the strength of the waves. Beaches usually alternate with cliffs. Recalling the preglacial irregularity of topography, you understand how Lake Erie could not be bordered by either continuous cliff or beach; in some parts one prevails and in some parts the other, but in no case can you travel many miles without finding both forms.

Along-shore currents. Under a fairly constant wind, the waves necessarily meet the shore, which is irregular, at various angles. If a wave strikes the shore directly, the water, after the impulse, settles back along the same line. With the continuance of oblique waves, the water is given a general movement along the shore. This constitutes an along-shore current, which is efficient in transporting the products of wave work.

Under-tow. When winds, even for an hour, drive waves against the shore, the water is piled up; and since a shoreward movement is continuous on the surface, the only escape for the accumulated water is along the bottom outward. This movement is called an "under-tow." The velocity of the under-tow depends directly on the strength of the winds causing water to accumulate along the shore. The higher the water becomes, the faster it will move down along the slope in response to gravity. An under-tow current, like any other water current, is a transporting agent. But, because of its relatively low velocity, the undertow carries only small material. These smaller pieces of sand, etc., represent the finer products of comminution by waves. As the result of deposition by undertow currents, the shore slope is gradually lessened.

Bays. Young shore lines are seldom even; but the denuding agencies of water tend always to straighten shore irregularities. Ultimately the oceans, in case of no change of level of sea or land, will change the most irregular shore line conceivable into an even line. Lakes, being short-lived, probably never accomplish this so perfectly.

The indentations of lake shore lines are due to headlands which represent the higher altitudes of the original stream-carved surfaces. Wave and current-work undercut and transport the degraded material of these headlands. The along-shore movement of the water distributes the materials thus acquired. Such a current, reaching a bay, is retarded both by the wave movement and by the mass of water in the deeper part of the bay. The velocity of the current being checked, its load is rapidly dropped. From the angle of the bay this deposited material gradually extends into deeper water; such a deposit is called a "spit." As the spit grows, a shallow water condition is maintained forward in the line of its axis, and the transporting current is able to move farther, before the on-shore movement of the deeper water in the bay checks the current and causes its load to drop. The influence of wave movement, in the deeper parts of the bay, manifests itself sometimes in bending the spit inland, developing a "hook." Later the spit may continue to grow in its original direction, and the hook will then appear as an irregularity on the land slope of the spit. Frequently a spit is developed also from the opposite side of the bay. In time the two may grow together constituting a "bar." A bar, however, seldom appears before the bay has been appreciably shallowed. There is a constant current moving out from the bay, in case it receives a constant supply of land drainage. Such a current keeps at least a narrow passage clear between the termini of the spits.

Spits are not always associated with bays. Sometimes such an accumulation starts and grows outward from a headland or even from the beach.

Water isolated from the lake by the development of a spit or a bar becomes a marsh. Vegetation gradually fills it in and the tract is added to the land. Bays, when shut off from the lake, pass through the marsh stage, at last becoming land. The abundant vegetation of these marshy areas, sometimes forming peat swamps, accounts for the muck soil found so extensively in the northwest

part of Ohio. During all three of the ice-front lake stages, the Maumee valley, which always had a very low slope towards the axis of the Lake Erie basin, contained a bay. The shallowness of the bay encouraged the growth of spits and bars, converting successive parts of it into a marsh. This history was repeated during the Maumee, Whittlesey and Warren stages. As a result there were developed in that part of Ohio hundreds of square miles of muck land, much of which had to be artificially drained by the early settlers. This land is very rich, and when brought under cultivation makes profitable farms. Smaller muck areas are found the whole length of the shore lines of these three lakes.

Other shore line structures. Along the lake front one sometimes sees a deposit of sand and gravel, growing directly out into the lake. This product of deposition, called "a cusp," is due to the interference of waves and currents, causing a deposition of the load in transit. As the cusp grows, the interference area is increased, and the deposit is extended more rapidly; but upon reaching deeper water it makes little progress. After attaining some size, bordering barriers may develop, and later be tied to the cusp. By this process, a lagoon is formed between the cusp and the barrier; it passes through the regular lagoon history, and thus increases the cusp's area. By a repetition of this process, as well as by extensions made similarly through the development of spits, the cusp attains large proportions, and is then called a "cuspate foreland."

Especially along shallow shores, the larger waves break a considerable distance from the coast. The wave "breaks" because its diameter or height is greater than the depth of the water. Along the line where "breakers" form, the action tends to pile up the material at the bottom. This process eventually develops a ridge on the bottom that in time shallows the water sufficiently to catch even the smaller waves. With the lapse of more time, the ridge appears above water as a line parallel to the coast proper. In reality it is a new beach, and is called a "barrier beach." When barrier beaches persist, they are usually connected with cusps or headlands in such a manner as to isolate the water between them and the original shore. This creates a marsh which passes through the various lagoon stages. The barrier beach then becomes a shore ridge.

Rivers flowing into a lake have their velocity checked by the

static water, and as a result deposit their loads. The products of stream erosion, thus deposited near the mouth of the river, build a "delta." Since streams vary with the seasons, in their velocity and volume, their loads are sometimes carried farther out into the lake before being deposited. If the volume and velocity were constant the year round, the river would shortly clog its own mouth and build a dam. Even under normal river conditions, deltas eventually attain such size that they rise above the lake level, and the stream takes one or several courses across it. Towns situated at the mouths of lake rivers are forced to make annual appropriations for dredging the stream, so as to keep the harbor open. Delta deposits gather rapidly, even at the mouths of old streams. Lake currents shift delta material somewhat, but never to the extent of distributing it all. About the borders of deltas, these currents form spits and barriers, which become a further menace to navigation.

The shores of islands have the same history as any other shore lines. If the island, through cliff development, furnishes an ample supply of material, lake currents will deposit spits, oriented with the prevailing wind. Sometimes barrier beaches are constructed, not infrequently, through the development of a bar the island may become land-tied. About all islands, we find the same catalogue of shore phenomena as are associated with the shore lines proper.

When the prevailing beach material is sand, dunes develop. The wind carries the sand in front of it, and, if the shore line lies athwart the wind, the dunes travel inland. Extensive dune areas are found in the northern part of the state, many miles south of the shore of Lake Erie. The material of these dunes represents the wave work of the high level lakes; they are especially abundant south of Sandusky, a typical area existing in the vicinity of Bellevue.

Geographic influences. Shore lines have elicited a variety of responses in man's activities. Long before anyone appreciated their significance, or even the former existence of ice front lakes, man used the old beaches for highways, frequently calling them "ridge roads." A high percentage in the linear extension of the beaches of the three ice-front lakes now carry highways. Even some of the spits, built into former bays, are used for roadbeds. In some localities, the three beaches are quite parallel for considerable distances; here the farms run from beach to beach, or the

interval between the beaches is divided between either shore. Where the beach ridges are a mile or less apart, the farms usually are narrow. Wherever sufficient muck land exists, and the area is within easy reach of a city, the farms are small; they are cultivated intensely, usually by market gardeners.

These ridges usually furnish the sand and gravel needed for structural purposes and for roadbeds. As concrete comes more generally into use, the economic advantage of the old shore lines will be even better appreciated. In several locations the material is adapted to the manufacture of sand brick; elsewhere I have seen the lake clays being used for tile, and for various other kinds of brick.

Quite a variety of soil is associated with these shore lines. The local rocks have had a great deal to do in determining the soil. In the region south of Sandusky, the denudation work of waves on the outcropping limestone has accumulated great areas of very clear silica, or sand. This silica existed in the limestone; the carbonates were entirely dissolved. In these areas peach orchards do well; melons and other vines appear also to thrive on the rolling sand hills.

The botanist has long been acquainted with the shifting facies of plant habitats, bordering shore lines. Even to-day one finds all the plant families within the limits of a bog habitat on the one hand, and a very dry sand dune on the other.

Post-glacial tilting. A shore line should be horizontal. If it is not horizontal, it has suffered tilting since it was made. Beaches of nearly all the ice-front lakes show deformation. This is not noted appreciably across northern Ohio, but the beaches of the same lakes when traced into Michigan or into New York do show tilting. The axis of movement was such that it is not so manifest in northern Ohio. It is possible, however, that a closer study of our shore lines may show that they are not horizontal. One appreciates why it is not an easy matter to tell exactly the water level of a shore line which has been subject to subaërial weathering for several thousand years; if it is a cliff cut in rock, it has suffered less change, and more accurate definition is possible. Up to date no one has gathered data that establish much information of the high-level lake beaches across Ohio. In New York state some of these ancient strands have been very appreciably tilted. In the first one hundred and twenty-five miles of direct

distance east of the Ohio-Pennsylvania state line, the Whittlesey beach rises 150 feet.[12] The Warren beach rises 42 feet between the east border of Ohio and Westfield, N. Y., a distance of 50 to 55 miles.[13] In a distance of 60 miles between Rome and Adams Center, N. Y., the Iroquois beach rises 235 feet.[14] These old shore lines do not show the same change in tilt; this fact suggests that the differential movement was in progress, as the lakes succeeded one another.

Land tilting in the St. Lawrence drainage basin is still in progress. Men have been watching it closely over half a century. It has been estimated that if the movement continues for 500 years, the tilt will have become sufficient to cause the upper Great Lakes to flow into the Mississippi valley by the old Chicago glacial lake outlet. The course of this outlet is now followed by the Chicago sewerage canal. This seems like a bold statement, but a study of altitudes shows that the tilt need not be very great to cause Lakes Michigan, Huron and Superior to flow southward past Chicago. Should this diversion be brought about, there will be very little water left to make a Niagara river. The falls will then cease to be of much importance.

[12] Leverett, *Monograph XLI*, U. S. Geol. Survey (1902), p. 756.
[13] *Ibid.*, p. 765.
[14] *Ibid.*, p. 774.